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TECHNICAL MEMORANDUM #3

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Date:	June 13, 2006	**KHA Proj. No.:**	011335022
From:	Stephen Leitch, P.E. J. Chris Ford, P.E.		
Subject:	Technical Memorandum # 3 – Surge Analysis Northeast Interceptor Evaluation		

1 Background

The Northeast Interceptor (NEI) is the critical link in conveying wastewater flow from a major portion of Wilmington, Wrightsville Beach, and New Hanover County to the Southside Wastewater Treatment Plant. Recent failures have led to concerns about the overall condition of the system. In order to address these issues, this study has been initiated to evaluate the capacity, condition, and reliability of the NEI System. As surge protection is integral providing a system that operates efficiently, reliably, and at maximum design conditions, a surge analysis has been performed as part of this study.

Under normal operating conditions, wastewater pumping systems operate at either a steady state condition (constant speed pumps), or a slowly varied condition (variable speed pumps). Constant speed pumps deliver a constant flow and head, while variable speed pumps deliver a slowly adjusted flow and head. Changes in system operation such as sudden pump failure, power failure, pump restart, and sudden valve closure can cause rapid changes in the velocity of the wastewater within the system. Velocity changes can cause pressures to fluctuate and vapor/air pockets to form and collapse at high spots along the force main, which in turn can generate large surge pressures. Lack of surge protection equipment, or improper sizing and location of surge protection equipment, may cause poor system performance, pipe failure, or mechanical equipment failure.

Surge models have been developed for the NEI to complete the following tasks:

- Evaluate potential surge pressures to aid in evaluating the adequacy of deteriorated pipe.
- Evaluate the adequacy/performance of the existing surge protection equipment, i.e. combination air/vacuum valves.
- Identify modifications that will minimize surge pressures and improve the operation and reliability of the system.

2 Document Review

The following documents, specific to the NEI system, were utilized as part of the surge analysis:

- Pump station and force main as-built drawings prepared by Henry Von Oesen & Associates dated December 5, 1983
- Evaluation of Pump Station 34 for Electrical Improvements prepared Ken Butler and Associates dated August 8, 2002
- Evaluation of Pump Station 34 for Electrical Improvements prepared Ken Butler and Associates dated August 9, 2002
- Greenville Loop Road Bridge at Riley's Branch As-Built Drawings prepared by W.K. Dickson dated March 25, 2003
- Independence Boulevard As-Built Drawings prepared by McKim & Creed dated February 22, 1989
- Northeast Interceptor Sewer Force Main Improvements prepared by McKim & Creed dated March 2006 (Preliminary)
- Pump and motor nameplate information (Appendix B), pump curve information (Appendix C), and drawdown tests as provided by the City of Wilmington
- Specifications for force main pipe and air valve, NEI Segment 1-Wrightsville Beach (Appendix D)

3 Methodology

The Northeast Interceptor System as defined for this study consists of two separate pumping systems. Pump Station 35 (COW PS 35 – Bradley Creek Pump Station), located near Bradley Creek at 6341 Oleander Drive, delivers flow via a 20-inch force main to gravity sewer just upstream of Pump Station 34 (COW PS 34 – Hewletts Creek Pump Station). Pump Station 34, located at 5915 Pine Grove Drive near Greenville Loop Road, delivers flow to the M'Kean Maffitt Wastewater Treatment Plant (Southside WWTP) via a 24-inch force main. Since the two systems are completely separate, a separate surge model was performed for each individual system.

A third pump station and force main, located on Wrightsville Beach, was designed and constructed as part of this system to convey wastewater from the Town of Wrightsville Beach to Pump Station 35. That system is commonly referred to as the Northeast Interceptor Segment 1. Because that system is solely owned and operated by the Town of Wrightsville Beach, it is not part of this study.

To analyze the surge potential of the NEI, both a steady state model and surge model were generated. The steady state model was generated in WaterCad which allows input of physical components of the system such as fittings, pipe size and type, wet wells, pumps, etc. The model produces normal steady state operating conditions such as pump flow and head. The data provided by the steady state model is an instantaneous “snapshot” view of the system during normal system operation with a constant outflow.

Once the steady state model was created, the WaterCad model was imported into Haestad’s Hammer program. Hammer is a transient analysis program used to assess the magnitude and extent of transient events within water and sewage systems such as pressure surges and sub-atmospheric pressures. The program is capable of modeling nearly any type of surge control equipment available such as combination air/vacuum valves, surge tanks, surge anticipator valves, surge relief valves, and gas vessels. The import feature of the Hammer Program allows transference of all steady state model data, including all physical characteristics and steady state hydraulic grade line information.

3.1 Steady State Model Input Data

The steady state models were generated from information obtained from the as-built drawings, the Shipyard Boulevard relocation plans, pump curves as provided by the City, and the Butler reports. Specifications for this portion of the NEI were not available; however, specifications were located for NEI Segment 1 (Wrightsville Beach). Because these specifications were produced by the same engineer and Segment 1 was part of the larger system that includes the facilities being evaluated in this study (Segment 2), we understand they are representative of what was specified for Segment 2. Pipe type and classes were obtained from these specifications so that actual inside pipe dimensions could be included in the model.

In order to evaluate an existing system or design improvements, the most extreme conditions must be developed and evaluated. To assess the highest potential surge conditions, the steady state model was created utilizing criteria that would produce a high flow, and thus the greater potential for higher surge conditions. To model the highest potential flows from each pump station, the following parameters were used; initial service Hazen-Williams C values (lower friction loss equates to higher flows), high wet well levels (lower static heads translate to higher flows), and operation of the largest capacity pump only. It is understood that interlocks within the existing control systems at each pump station do not allow Pumps No. 3 and 4 to operate concurrently. Therefore, the largest anticipated flow was assumed to occur with only the largest capacity pump in operation. Table TM 3.1 below shows the parameters that were used for each pump station.

Table TM 3.1 – Steady State Model Parameters

Criteria		Pump Station 34	Pump Station 35
Hazen –Williams C	Ductile Iron	125	125
	HDPE	140	-
	PVC	140	140
Pump Station Water Level (feet)		-6.25	-5.50
Pump In Operation		No. 4	No. 3

Accurate pump curves are critical for prediction of flow and head during a surge event, as well as for prediction of steady state operating conditions. Pump curves were provided by the City for all pumps at each pump station. While most of the pump curves were certified curves, specific to each pump, the only available curve for Pump No. 4 at Pump Station No. 35 was a catalog curve. The curve utilized for this pump was estimated based upon the design point of 6,600 gpm at 175 feet presented in the Butler Report. Using this design point, an estimated curve was developed which passed through this point on the catalog curve. The pump curves are included in Appendix C.

3.2 Surge Model Input Data

The initial input data for the surge model is the data utilized to generate the steady state model. This data is inserted in the surge model by importing the steady state into the surge program. Additional input data that is required for the surge model data include the wave speeds for each combination of pipe type and size and the estimated inertias of the pump and motors. Wave speeds reflect the speed at which pressure pulses can propagate through a system which can affect the magnitude of pressure waves within a system. The magnitude of the wave speed is dependent on the size of the pipe and the material. Generally rigid pipes such as ductile iron produce higher wave speeds while elastic pipes such as HDPE and PVC produce lower wave speeds.

The NEI system consists of three types of material; DIP, PVC, and HDPE. To determine the wave speed for DIP, the equation developed by Korteweg was utilized as provided in the Hammer program documentation. This formula is appropriate for materials that have a diameter to thickness ratio which is greater that 40. Equation variables include the modulus of elasticity, bulk modulus of water, pipe inside diameter, pipe wall thickness, and the density of water.

Since the diameter to thickness ratio of PVC and HDPE is less than 40, the Korteweg equation can not be used for these materials. The equations provided in AWWA C900 (PVC pipe) and AWWA C906 (PE pipe) were used to estimate wave speed values. Equation variables include the modulus of elasticity, bulk modulus of water, pipe inside diameter, and pipe wall thickness. The values used for wave speed for all materials are provided in Table TM 3.2 below. The calculations are included in Appendix A.

Table TM 3.2 – Wave Speed Values

Material	Nominal Size (in)	Pump Station	Wave Speed (ft/s)
DIP	12	34 and 35	3,995
	16	34 and 35	3,865
	18	34	3,801
	20	35	3,744
	24	34	3,645
PVC	24	34	1,103
	30	34	1,103
HDPE	24 (19.7" id)	35	1,250
	24 (21" id)	34	1,109

Pump and motor inertias are critical when assessing pump failures and restarts. The inertia of the pump and motor relates to the speed at which the pump slows down once power is shut down. The higher the inertia of the pump, the longer it takes to bring the pump and the water column to a stop. A high inertia can play a large role in minimizing surge potential by absorbing the energy from the water column slowly after a pump shut down or failure, allowing the water column velocity to slowly decrease.

Due to the age of the pumps and the limited information that was available, the inertias for the pumps and motors had to be estimated. The inertia estimate was based upon the equation derived by Thorley and presented in the Hammer documentation. The inertias are dependent upon the rotational speed of the pump and the brake horsepower of the pump at the best efficiency point of the curve. The estimated inertias are shown in Table TM 3.3 below. Due to the fact that peak flows were utilized for the surge analysis, only pump No. 4 at Pump Station No. 34 and pump No. 3 at Pump Station No. 35 were utilized since they are the largest pump at each station. Calculations are shown in the appendix.

Table TM 3.3 – Pump and Motor Inertia Values

Pump Station / Pump	Item	Moment of Inertia ($kg \cdot m^2$)
34 / No. 4	Pump	2.91
	Motor	15.39
35 / No. 3	Pump	2.20
	Motor	3.71

3.3 Surge Analysis

The general philosophy for the surge analysis consisted of analyzing the existing pumping system and subsequently performing analyses to determine if modifications could be made to improve the system's surge mitigation performance. For the purposes of this surge analysis, it was determined that the conditions to be modeled for a surge event would be a power failure followed by a pump restart. This situation will result in larger extreme pressures than just a power failure if the pump is restarted before transient energy from the initial pump shutdown has dissipated. A dramatic system change such as a power failure and restart can cause negative pressures to occur within the force main, which causes liquid to evaporate and form a vapor pocket. A large vapor pocket can cause a separation of the water column. Once the pressure rises above zero, the vapor pocket will dissipate and collapse allowing the water columns to rejoin. The rejoining of the water column can cause large pressure surges which travel throughout the system. Information gleaned from this scenario allows for identification of areas critical to this particular system, and identifies areas requiring surge protection equipment.

For each scenario, the system was first modeled with no surge protection, i.e. no combination air/vacuum valves or other surge protection equipment. This provides a worst case baseline to work from in regards to potential sub-atmospheric pressures, vapor pocket formation, and surge pressures. This also represents the current system which has only air release valves and not combination air/vacuum valves. Air release valves, which are not designed for surge protection, are designed to release air automatically as it accumulates while the system is in operation and under pressure. Combination air/vacuum valves provide surge protection by exhausting large volumes of air as the system is being filled and permitting air to enter the line when a vacuum is drawn.

Once the system was analyzed with no surge protection, combination air/vacuum valves were modeled at the 12 existing ARV locations shown on the as-built drawings. Two sizes were modeled, a 1-inch valve and a 2-inch valve. These sizes were evaluated to determine which size provided the greatest amount of surge mitigation. The air release valve small orifice was modeled as 3/16" diameter for Pump Station 35 and 5/16" diameter for the Pump Station 34. The small orifice size was based upon standard valve sizing literature. The size was not varied during the analysis since this orifice does not significantly impact surge mitigation. The small orifices main purpose is for air release during normal operations.

Upon determination of the most effective size combination air / vacuum valve, the force main profile was analyzed to determine potential locations for additional valves. Once locations were identified, combination air / vacuum valves were modeled in the system to determine their impact on surge mitigation within the force main.

In summary, the following surge scenarios were modeled in Hammer:

- Pump Station 35
    - Without surge protection
    - With 2-inch combination air / vacuum valves
    - With 1-inch combination air / vacuum valves
    - With additional combination air / vacuum valves at potential problem locations

- Pump Station 34
    - Initial system without surge protection
    - Revised system including the Shipyard Blvd. relocation without surge protection
    - Revised system including the Shipyard Blvd. relocations with 2-inch combination air/ vacuum valves
    - Revised system including the Shipyard Blvd. relocation with 1-inch combination air/ vacuum valves

- Revised system including the Shipyard Blvd. relocation with additional air / vacuum valves at potential problem locations

4 Pump Station 35 Analysis

The Pump Station 35 system was analyzed with Pump No. 3 in operation delivering approximately 4,422 gpm at 75 feet. The pump station was then modeled with a pump shutdown/failure and subsequent restart. The results were analyzed to determine the location and magnitude of the surge pressures generated in the system, the extent to which the system experiences sub-atmospheric pressures, and the location of vapor pockets which are formed due to extended periods of sub-atmospheric pressures. The pump failure and restart scenario was also analyzed to determine the systems sensitivity to the duration between failure and restart. This was done through an iterative process by modeling varying durations to determine the duration which generated the highest pressures. Through this iterative process, it was determined that 30 seconds generated the highest surge pressures within the system. The results for the three scenarios modeled for Pump Station 35 are included in Table TM 3.4. These values reflect a 30 second restart.

During investigation of Pump Station 35 we observed a surge relief valve installed on the discharge piping of Pump No. 4. After several conversations with City personnel it was determined that no specific technical information other than the model number was available. Due to the limited amount of available information and unknown condition of the valve, it was not included in the model. This represents a more conservative scenario.

4.1.1 Without Protection

The without protection scenario shows a maximum surge pressure of approximately 145 psi. As seen on Figure 1 and 2, this pressure occurs roughly throughout the entire force main. Analysis of the cause for the maximum surge pressure indicated that sub-atmospheric pressures are contributing to the formation of vapor pockets at high spots along the force main. The collapse of these vapor pockets cause a large upsurge in pressure which reflects throughout the system. Figures 1 and 2 also indicate the entire pipeline is subject to full vacuum pressures during the scenario.

The largest vapor pocket is formed at ARV #12. The volume of this vapor pocket is significant enough to allow for a complete water column separation. Once the pump is restarted, the pressure within the force main rises and the vapor pocket collapses. When this occurs, the separated water columns collide causing an upsurge in pressure that reflects throughout the entire system. An analysis of the time histories for each high spot location indicated that the maximum surge pressures at each of these locations is caused by the vapor pocket collapse at ARV #12, as opposed to the collapse of the vapor pockets at each individual location. This indicated that the most critical location for surge control is the high spot at ARV #12. The time history for ARV # 12 is provided in Figures 3 and 4. Time history figures show the flow, pressure, and air/vapor volume upstream and downstream of a node in the system (ARV #12 in this instance). For each node within the system there are two pipes which connect to create the node. While pressure will remain constant upstream and downstream of the node, the volume and flow can vary from upstream to downstream depending on the characteristics of the system, the direction of flows, and the presence of separation or converging of water columns.

4.1.2 With 2-inch Combination Air / Vacuum Valves

This scenario utilized 2-inch combination air/vacuum valves (CAVV) assemblies at all current ARV locations; ARV #8 through ARV #12 (ARV #7 was not included since the system transitions from pressure to gravity at that location). Figures 5 and 6 indicate a maximum surge pressure of 110 psi for this scenario, a 24% reduction in surge pressure from the no protection scenario. However, a significant amount of full vacuum pressures still occurred during the scenario.

The CAVV assemblies are located where vapor pocket formation was observed in the without protection scenario, with the exception of three locations; two near Riley's Branch on Greenville Loop Road and one near Greenville Loop Road and Twin Magnolias Lane. CAVV's are designed to allow air into the pipe to prevent sub-atmospheric pressures and also to allow air to exit the pipe once the pump restarts, allowing the water columns to rejoin.

Analysis of the high spots indicated that air is being drawn into the pipe during pump shutdown, with the largest volumes located at ARV #12, #11, and #10. The air is then exhausted after pump restart. Further analysis indicated that there is a large upsurge in pressure generated when the air pocket is exhausted at ARV #12. This upsurge in pressure, much like the scenario without protection, reflects throughout the force main as can be seen on the time histories for the ARV locations. This upsurge is attributed to water column reformation when the air is exhausted. Proper sizing of CAVVs allows for a pressurization of the air pocket before it is exhausted, providing an air cushion when the water column rejoins. According to the time histories for ARV #12 (Figures 7 & 8) there is little to no cushioning provided with the 2-inch CAVV and thus a large upsurge is generated. While the other high spot locations experience the same effect as ARV #12, their upsurge is minor compared to the pressure experienced as a result of the water column reformation at ARV #12.

Also of significance is the effect of the upsurge due to water column reformation on the minimum pressures generated. The large upsurge generated at ARV #12 is reflected through the system as a wave with alternating signs, i.e. positive pressure, then negative pressure. Therefore, the large upsurge generated by the water column reformation at ARV #12 is a direct cause of the extensive negative pressures throughout the system. A reduction in the upsurge pressures through proper CAVV sizing can lead to a reduction in negative pressures observed.

4.1.3 With 1-inch Combination Air / Vacuum Valves

The 2-inch CAVV scenario indicated that the 2-inch CAVV's were allowing air into and out of the force main, but were not allowing pressurization of the air prior to being expelled. This caused a significant upsurge in pressure that was reflected throughout the system. As an attempt to alleviate this problem, the CAVV's were modeled as 1-inch valves.

Table TM 3.4 – Pump Station 35 Surge Model Results

Parameter			Without Protection		With 2-inch Combination Air / Vacuum Valves		With 1-inch Combination Air / Vacuum Valves		Additional Valves	
			Value	Figure	Value	Figure	Value	Figure	Value	Figure
Maximum Surge Pressure (psi)			145	1 & 2	110	5 & 6	60	9 & 10	63	13 & 14
Vapor / Air Pocket Locations – Max. Pressure	Ex. ARV #12 (1,345)*	Valve (Y/N)	No	3 & 4	Yes	7 & 8	Yes	11 & 12	Yes	15 & 16
		Pressure (psi)	130		92		45		48	
	Ex. ARV #11 (3,587)*	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	130		90		54		58	
	Ex. ARV #10 (5,868)*	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	137		95		52		58	
	Sta. 95+00 (6,995)*	Valve (Y/N)	No	-	No	-	No	-	Yes	-
		Pressure (psi)	131		88		50		55	
	Ex. ARV #9 (9,012)*	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	138		92		48		54	
	Ex. ARV #8 (12,295)*	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	139		91		33		53	
	Sta. 29+00 (13,595)*	Valve (Y/N)	No	-	No	-	No	-	Yes	-
		Pressure (psi)	116		96		28		52	
	Sta. 19+00 (14,595)*	Valve (Y/N)	No	-	No	-	No	-	Yes	-
		Pressure (psi)	109		71		20		24	
Full Vacuum Pressure Exists? / Approximate Extent			Yes / Throughout		Yes / Approximately 92% of Length		Yes / Approximately 19% of Length		Yes / Approximately 10% of Length	

*Values shown below ARV/ Station number corresponds to the location of that item on the attached figures

As can be seen in Table TM 3.4, and Figures 9 and 10, a reduction in valve size to 1-inch reduced the maximum surge pressure to 60 psi, a reduction of 59% from the without protection scenario and 45% from the 2-inch valve scenario. Analysis of the time histories for ARV's #12, #11, and #10 indicate that pressurization occurs prior to the exhaustion of the air pockets. Pressurization is shown as a pressure rise at the node just prior to the air volume at the node reaching zero. Figures 11 and 12 show this pressurization for ARV #12. This pressurization reduces the upsurge that is generated when the water column combines. The reduction in the upsurge at these locations also reduced the extent of negative pressures seen along the force main as seen in Figures 9 and 10. While negative pressures are occurring, they occur for short periods of time and do not seem to have an adverse effect on the system as a whole.

4.1.4 With Additional Combination Air / Vacuum Valves

Several locations were identified along the force main for potential location of new ARV structures. They include both sides of Riley's Branch on Greenville Loop Road and also near Greenville Loop Road and Twin Magnolias Lane. These areas showed small vapor pocket formation during the without protection scenario and therefore were considered for location of new ARV's. Figures 13 and 14 indicate a maximum surge pressure within the system of 63 psi, a slight increase above the 1-inch valve scenario. Table TM 3.4 also shows a slight increase in pressure at all of the locations identified (time histories are shown for ARV #12 on figures 15 and 16). However, Figures 13 and 14 also indicate a reduction in the extent of full vacuum negative pressures within the system.

4.1.5 Summary of Pump Station 35 Surge Modeling

Modeling of the Pump Station 35 pumping system indicated several locations of vapor pocket formation when no surge protection was provided. Vapor pockets were observed at eight locations with the largest occurring where ARV #12 is located. Modeling of the system with no surge protection indicated that a maximum surge pressure of 145 psi is possible, with coinciding negative pressures throughout the system. These pressures are a direct result of vapor pocket formation and collapse and are similar to what might be experienced with inoperable air valves.

Modeling indicated that the existing ARV's are located at areas where vapor pocket formation could occur. Modeling also indicated that 2-inch CAVV's are oversized and will not allow the air exiting the force main to be compressed. The use of a smaller 1-inch ARV allowed pressurization of the exhausting air and significantly reduced the surge pressure while greatly reducing the amount vacuum pressures seen within the system.

Additional 1-inch ARV's were modeled at the three additional locations where vapor pocket formation occurred during without protection modeling. As Table TM 3.4 indicated, these additional valves did reduce the amount of negative pressures within the system, though they slightly increased the maximum surge pressures. This is still considered an improvement in surge mitigation since elimination of negative pressures eliminates vapor pockets.

4.1.6 Pump Station 35 Recommendations

Based on the surge analysis of the Pump Station 35 system, we recommend the following:

1. Install combination air/vacuum valves with a 1-inch large orifice and 3/16” small orifice at all current ARV locations (ARV’s #8-#12). The 1-inch combination ARV valves will reduce the anticipated overall total pressure under surge conditions approximately 45% and reduce the extent of full vacuum pressure from approximately 92% of the system to approximately 19%.

2. Investigate the condition of the existing surge relief valve within Pump Station 35. Repair or replace as necessary.

It is understood that the City is considering utilizing ARI combination air / vacuum valves. Due to the size of the large orifice (1.246 in^2) these valves are anticipated to provide surge mitigation that approximates that provided by the 1-inch scenario. It is suggested that Model D-020 be utilized with a large orifice area of 1.246 in^2 and a 0.018 in^2 small orifice area. The connection size should be at least 2-inch.

Installation of additional ARV assemblies is not necessary and not recommended. While the installation of new 1-inch combination air/vacuum valves on each side of the Riley’s Branch crossing and also near Greenville Loop Road and Twin Magnolias Lane does improve the system slightly by reducing the extent of full vacuum pressures, the reduction is minimal and does not justify the additional expense and operation and maintenance.

5 Pump Station 34 Analysis

Pumping Station 34 is unique compared to Pump Station 35 in that a portion of the system is scheduled for a piping and alignment modification. Due to deterioration of the 24-inch ductile iron pipe along Shipyard Boulevard, a portion of the force main will be replaced and relocated with 30-inch PVC force main.

Due to the changes being made to the system, the existing pumping system was only modeled to determine current surge conditions and to evaluate the performance of the existing surge mitigation system. Once this was completed, the system was modeled with the Shipyard replacement without protection and with options for designed protection.

5.1.1 Initial System

The Pump Station 34 system was analyzed with Pump No. 4 in operation delivering approximately 7,735 gpm at 162 feet. The pump station was then modeled with a pump shutdown/failure and subsequent restart. The results were analyzed to determine the location and magnitude of the surge pressures generated in the system, the extent to which the system experiences sub-atmospheric pressures, and the location of vapor pockets which are formed due to extended periods of sub-atmospheric pressures. The pump failure and restart scenario was also analyzed to determine the systems sensitivity to the duration between failure and restart. This was done through an iterative process by modeling varying durations to determine the duration which generated the highest pressures. Through this iterative process it was determined that 30 seconds generated the highest surge pressures within the system. The results for the scenario modeled for the existing Pump Station 34 system are included in Table TM 3.5. These values reflect a 30 second restart.

5.1.1.1 Without Protection

Figures 17 and 18 indicate maximum surge pressure of 191 psi. Analysis of the cause for the maximum surge pressure indicated that sub-atmospheric pressures are contributing to the formation of vapor pockets at high spots along the force main. Figures 17 and 18 indicate that there are approximately five locations where vapor pocket formation occurs. The largest of the vapor pockets occur upstream of ARV #5 and at ARV #4. When these vapor pockets collapse they cause a large upsurge in pressure that affects the entire system. Analysis of the individual vapor pockets indicate that those near ARV #5 and ARV #4 are causing the maximum system pressures (191 psi near ARV #5 and 171 psi near ARV #3). ARV #5 and ARV #4 are therefore the critical locations for surge mitigation. These pressure surges, which occur after the vapor pockets collapse, also cause extensive full vacuum pressures throughout the system.

5.1.1.2 Discussion of Pump Station 34 Existing System

The existing Pump Station 34 system is capable of producing significant surge pressures, up to 191 psi (no protection). The system is comprised of Class 50 DIP and C905 DR 25 PVC pipe. The Class 50 DIP has a working plus surge pressure rating which is approximately 350 psi (250 psi pressure rating plus 100 psi surge allowance), which is well below the maximum anticipated surge pressure with no protection. However, corrosion of the DIP pipe could reduce the wall thickness and correspondingly reduce the pressure capacity of the pipe. The potential reduction in capacity due to corrosion of the DIP should be considered in the condition assessment.

C905 DR25 PVC pipe provides a maximum pressure rating of 165 psi based on a factor of safety of two (also used for DIP design), with no allowance for surge pressures. It is understood that the only PVC within the current system is located along Independence Boulevard. Analysis of the system shows that the maximum anticipated pressure in this section is 148 psi, which is within the pipes pressure rating.

Table TM 3.5 –Pump Station 34 Existing System Surge Model Results

<table>
<tr><th colspan="3" rowspan="2">Parameter</th><th colspan="2">No Protection</th></tr>
<tr><th>Value</th><th>Figure</th></tr>
<tr><td colspan="3">Maximum Surge Pressure (psi)</td><td>191</td><td>17 & 18</td></tr>
<tr><td rowspan="12">Vapor / Air Pocket Locations – Max. Pressure</td><td rowspan="2">ARV #6</td><td>Valve (Y/N)</td><td>No</td><td rowspan="2">-</td></tr>
<tr><td>Pressure (psi)</td><td>169</td></tr>
<tr><td rowspan="2">ARV #5</td><td>Valve (Y/N)</td><td>No</td><td rowspan="2">-</td></tr>
<tr><td>Pressure (psi)</td><td>157</td></tr>
<tr><td rowspan="2">ARV #4</td><td>Valve (Y/N)</td><td>No</td><td rowspan="2">-</td></tr>
<tr><td>Pressure (psi)</td><td>119</td></tr>
<tr><td rowspan="2">ARV #3</td><td>Valve (Y/N)</td><td>No</td><td rowspan="2">-</td></tr>
<tr><td>Pressure (psi)</td><td>111</td></tr>
<tr><td rowspan="2">ARV #2</td><td>Valve (Y/N)</td><td>No</td><td rowspan="2">-</td></tr>
<tr><td>Pressure (psi)</td><td>108</td></tr>
<tr><td rowspan="2">ARV #1</td><td>Valve (Y/N)</td><td>No</td><td rowspan="2">-</td></tr>
<tr><td>Pressure (psi)</td><td>92</td></tr>
<tr><td colspan="3">Full Vacuum Pressure? / Approximate Extent</td><td colspan="2">Yes / Throughout</td></tr>
</table>

5.1.2 Pump Station 34 System Including the Shipyard Relocation

The Pump Station 34 system including the Shipyard relocation was analyzed with Pump No. 4 in operation delivering approximately 7,831 gpm at 161 feet. The pump station was then modeled with a pump shutdown/failure and subsequent restart. The results were analyzed to determine the location and magnitude of the surge pressures generated in the system, the extent to which the system experiences sub-atmospheric pressures, and the location of vapor pockets which are formed due to extended periods of sub-atmospheric pressures. The pump failure and restart scenario was also analyzed to determine the systems sensitivity to the duration between failure and restart. This was done through an iterative process by modeling varying durations to determine the duration which generated the highest pressures. Through this iterative process it was determined that 30 seconds generated the highest surge pressures within the system. The results for the scenarios modeled for the Pump Station 34 system are included in Table TM 3.6. These values reflect a 30 second restart.

5.1.2.1 Without Protection

The without protection scenario indicated a maximum surge pressure of 233 psi. As indicated on Figures 19 and 20 the maximum pressures are primarily between Pump Station 34 and Shipyard Boulevard. This maximum pressure, located within a DIP section of the force main, is within the range of Class 50 DIP (250 psi plus 100 psi surge allowance). It is understood that C905 DR25 PVC is utilized in two sections of the Pump Station 34 system in this scenario; along Independence Boulevard and at the Shipyard relocations. Closer inspection of the modeling results indicates a maximum pressure at these locations of 131 psi and 114 psi respectively. These pressures are within the 165 psi rating of the PVC pipe.

Analysis of the cause of the maximum surge pressures indicated that vapor pockets are forming near ARV #5 and ARV #4 due to sub-atmospheric pressures throughout the pipeline. As these vapor pockets collapse they cause pressure upsurges which reflect throughout the system. Figures 19 and 20 also indicate that the entire pipeline is subject to full vacuum pressures during this scenario.

The large vapor pockets that form near ARV #5 and ARV #4 are significant enough to allow for complete water column separation. Once the pump is restarted, the pressure in the pipeline rises and allows the vapor to condense to the point that the vapor pocket collapses and the water column rejoins. The collision that occurs when the water columns rejoin causes the pressure upsurge at that location. Analysis of the areas near ARV #5 and ARV #4 indicate that these areas are critical in controlling the surge generated within the system as these areas create the largest upsurges upon pump restart.

5.1.2.2 With 2-inch Combination Air / Vacuum Valves

This scenario utilized 2-inch CAVV assemblies at all current ARV locations (ARV #1- ARV #6). As can be seen in Table TM 3.6 and Figures 21 and 22, the inclusion of these valves reduces the maximum surge pressure to 100 psi and significantly reduces the amount of full vacuum pressures within the system.

Generally, the modeled CAVV locations are at areas which exhibit vapor pocket formation in the without protection scenario. The two CAVV's which replace ARV #5 are located at the downstream end of a series of vapor pockets indicated in the without protection model. The CAVV at Sta. 217+41 coincides with the most downstream vapor pocket. This overlap allows the CAVV's at Sta. 217+41 and Sta. 211+81 provide adequate venting capacity and prevent formation of vapor pockets in the vicinity of the CAVV's.

Analysis of the high spots indicate that air is being drawn into the pipeline during the shutdown at those locations, with the largest volumes of air at the new valve at Sta. 217+41 (upstream of old ARV #5) and ARV #4. These volumes of air were shown to be exhausted from the pipeline after pump restart. Further analysis indicated that pressure upsurges were generated when the air pocket was exhausted at each of these valves. The upsurges in pressure from these two ARV's are the main cause for the pressure surges within the system. The air pocket collapse at Sta. 217+41 (upstream of old ARV #5, Figures 23 and 24) causes higher pressures from Pump Station 34 to ARV #4 and the air pocket collapse at ARV #4 (Figures 25 and 26) causes higher pressures from ARV #4 to the Southside Wastewater Treatment Plant.

Proper air valve sizing allows for pressurization of an air pocket prior to being exhausted from the pipeline. This provides a cushioning effect to the rejoining water columns. According to the time histories for the CAVV at sta. 217+41, Figures 23 and 24, the 2-inch CAVV is allowing pressurization of the air at the CAVV location. However, it appears that a decrease in flow occurs at the same time and may be causing some of the pressure increase. Similarly at ARV #4 the time histories, Figures 25 and 26, indicate that pressurization is occurring prior to the air being expelled, allowing cushioning and a lower upsurge.

5.1.2.3 With 1-inch Combination Air / Vacuum Valves

The previous scenario modeled 2-inch valves at all current ARV locations. While the 2-inch valves appeared to operate adequately, the cushioning provided was minimal at ARV #5. In an attempt to provide some cushioning, 1-inch CAVV's were modeled.

As can be seen in Table TM 3.6 and Figures 27 and 28, reducing the valve sizes to 1-inch reduces the maximum pressure within the pipeline to 98 psi, roughly equivalent to the 2-inch CAVV scenario. Analysis of the CAVV at Sta. 217+41 indicated that pressurization does occur with the 1-inch valve, which in turn decreases the upsurge pressure due to the air pocket collapsing just as with the 2-inch CAVV scenario. The time histories for this CAVV are shown on Figures 29 and 30. ARV #4's time histories are included as well in Figures 31 and 32.

5.1.2.4 With Additional Combination Air / Vacuum Valves

Initial modeling of the system with no protection and a review of the profile indicated three potential locations for additional CAVV's as follows:

1. near the intersection of College Road and Cascade Drive
2. near Ole Time Pottery along Shipyard Boulevard, and
3. near the intersection of Longstreet Drive and Stonewall Jackson Drive.

These locations showed sudden grade changes that could potentially cause vapor pocket formation. In order to evaluate the benefit of additional CAVV's at these locations, 1-inch CAVV's were inserted into the model at all existing ARV locations. As can be seen in Table TM 3.6 and Figures 33 and 34, the inclusion of these additional CAVV assemblies reduces the maximum surge pressures within the system slightly as compared to the 2-inch and 1-inch valve scenarios. Inspection of these figures also indicates that the valves also slightly reduced the amount of full vacuum that is experienced within the force main. The overall benefit of the additional valves, however, is minimal.

Table TM 3.6 – Pump Station 34 with Shipyard Relocation Surge Model Results

Parameter			No Protection		With 2-inch Combination Air / Vacuum Valves		With 1-inch Combination Air / Vacuum Valves		With Additional Valves	
			Value	Figure	Value	Figure	Value	Figure	Value	Figure
Maximum Surge Pressure (psi)			233	19 & 20	100	21 & 22	98	27 & 28	97	33 & 34
Vapor / Air Pocket Locations – Max. Pressure	Ex. ARV #6 (4678’)	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	170		87		82		78	
	Sta. 250+00 (7548’)	Valve (Y/N)	No	-	No	-	No	-	Yes	-
		Pressure (psi)	163		82		63		52	
	Sta. 237+14 (8834’)	Valve (Y/N)	No	-	No	-	No	-	Yes	-
		Pressure (psi)	150		77		48		47	
	Sta. 217+41 (10807’)	Valve (Y/N)	No	-	Yes	23 & 24	Yes	29 & 30	Yes	-
		Pressure (psi)	100		69		44		40	
	Sta. 211+81 (11367’)	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	101		72		44		40	
	Ex. ARV #5 (11498’)	Valve (Y/N)	No	-	No	-	No	-	Yes	-
		Pressure (psi)	100		73		45		40	
	Sta. 192+00 (13348’)	Valve (Y/N)	No	-	No	-	No	-	Yes	-
		Pressure (psi)	128		72		47		43	
	Ex. ARV #4 (18592’)	Valve (Y/N)	No	-	Yes	25 & 26	Yes	31 & 32	Yes	-
		Pressure (psi)	109		56		26		29	
	Ex. ARV #3 (23016’)	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	127		64		29		30	
	Ex. ARV #2 (28572.66’)	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	102		60		26		29	
	Ex. ARV #1 (30477’)	Valve (Y/N)	No	-	Yes	-	Yes	-	Yes	-
		Pressure (psi)	79		47		21		21	
Full Vacuum Pressure? / Approximate Extent			Yes / Throughout		Yes / Approximately 12% of Length		Yes / Approximately 5% of Length		Yes / Approximately 6% of Length	

5.1.2.5 Summary of Pump Station 34 Modeling

Modeling of the Pump Station 34 system indicated several locations of vapor pocket formation when no surge protection was provided. Vapor pockets were observed at five locations with the largest pockets forming near ARV #4 and in the vicinity of ARV #5. Collapse of these pockets in the without protection scenario indicated a maximum surge pressure of 233 psi and full vacuum pressures throughout the system. The negative pressures are a direct result of vapor pocket formation and collapse and are similar to what might be experienced with inoperable air valves.

Modeling of the 2-inch CAVV and 1-inch CAVV surge protection scenarios indicated that CAVV's at current ARV locations can provide proper venting of the pipeline and also showed no vapor pocket formation at non-ARV locations. The inclusion of 2-inch air valves and 1-inch air valves reduced the overall maximum surge pressure to 100 psi and 98 psi respectively, and each greatly reduced the amount of full vacuum conditions that were seen in the pipeline. Additional valves only provided minimal improvement in the system.

5.1.3 Pump Station 34 Recommendations

Based on the surge analysis of the Pump Station 35 system, the following is recommended:

1. Install combination air/vacuum valves with a 1-inch large orifice and a 5/16" small orifice at current ARV locations (ARV #1-#4 and #6) and proposed locations within the Shipyard relocation project. The 1-inch combination ARV valves will reduce the anticipated overall total pressure under surge conditions approximately 58% and reduce the extent of full vacuum pressure from approximately 100% of the system to approximately 13%.

It is understood that the City is considering utilizing ARI combination air / vacuum valves. Due to the size of the large orifice (1.246 in^2) these valves are anticipated to provide surge mitigation that approximates that provided by the 1-inch scenario. It is suggested that Model D-020 be utilized with a large orifice area of 1.246 in^2 and a 0.018 in^2 small orifice area. The connection size should be at least 2-inch.

Installation of additional ARV assemblies is not necessary and not recommended. While the installation of new 1-inch combination air/vacuum valves near the intersection of College Road and Cascade Drive, near Ole Time Pottery along Shipyard Boulevard, and near the intersection of Longstreet Drive and Stonewall Jackson Drive does improve the system slightly by reducing the extent of full vacuum pressures, the reduction is minimal and does not justify the additional expense and operation and maintenance.

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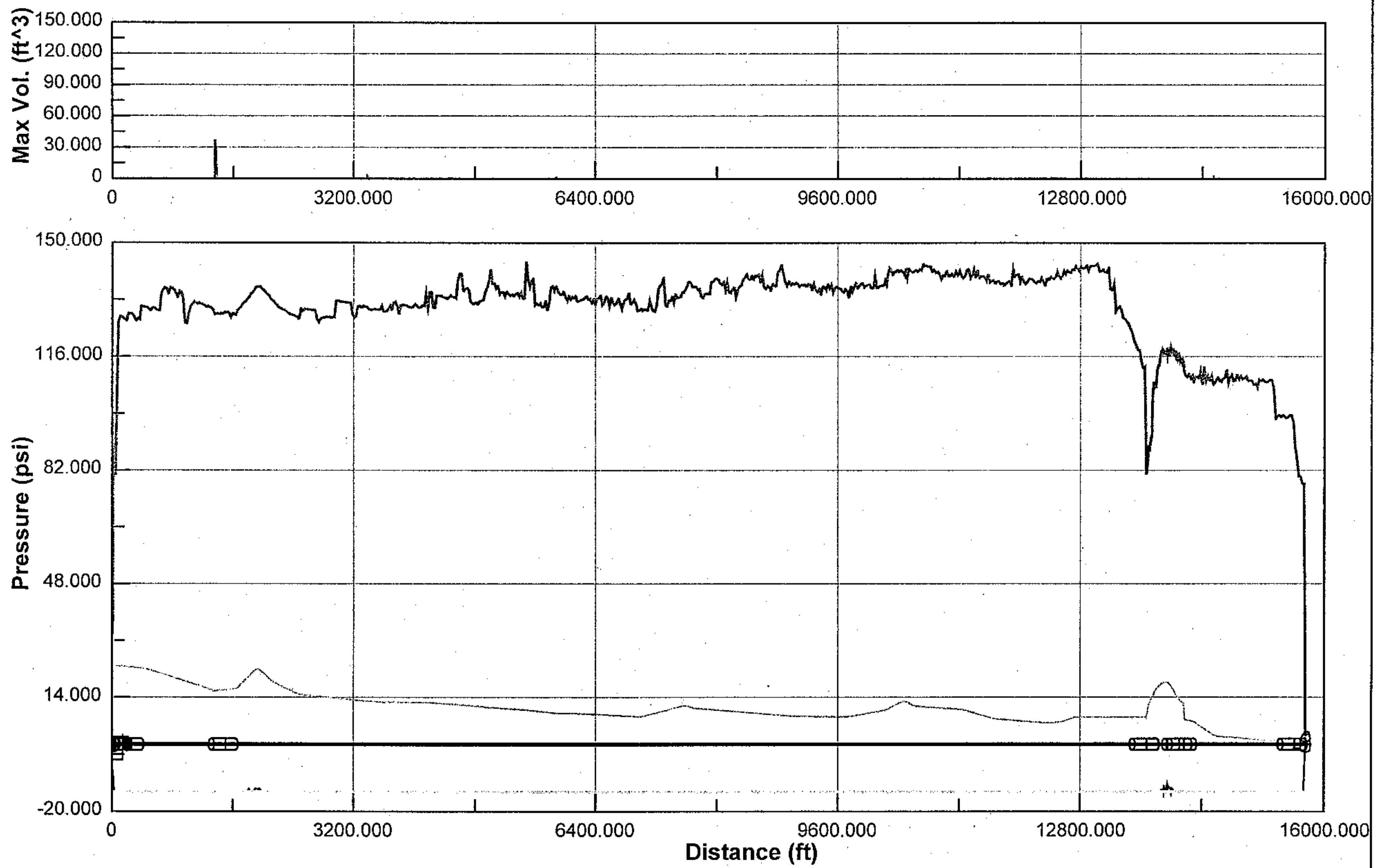
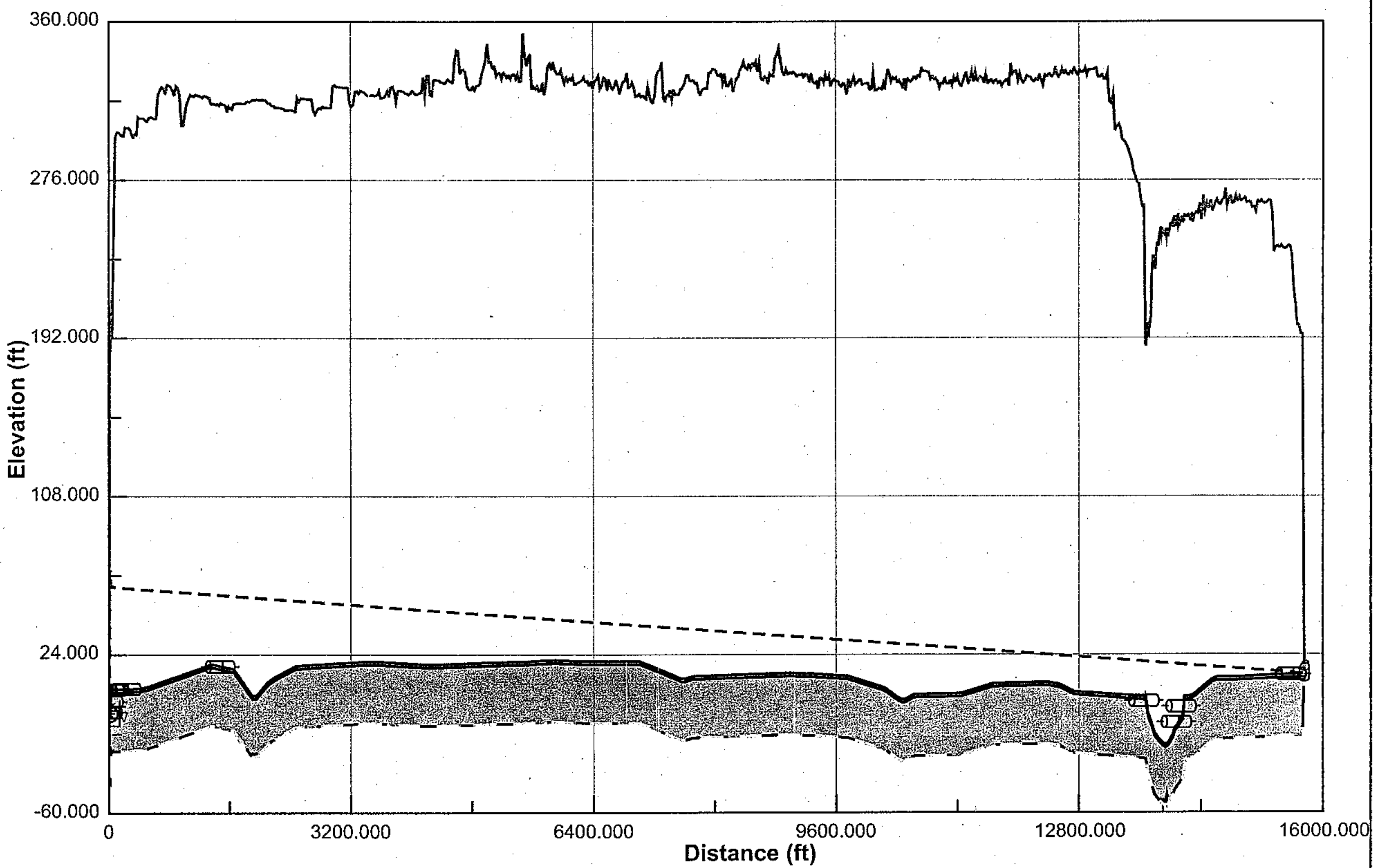
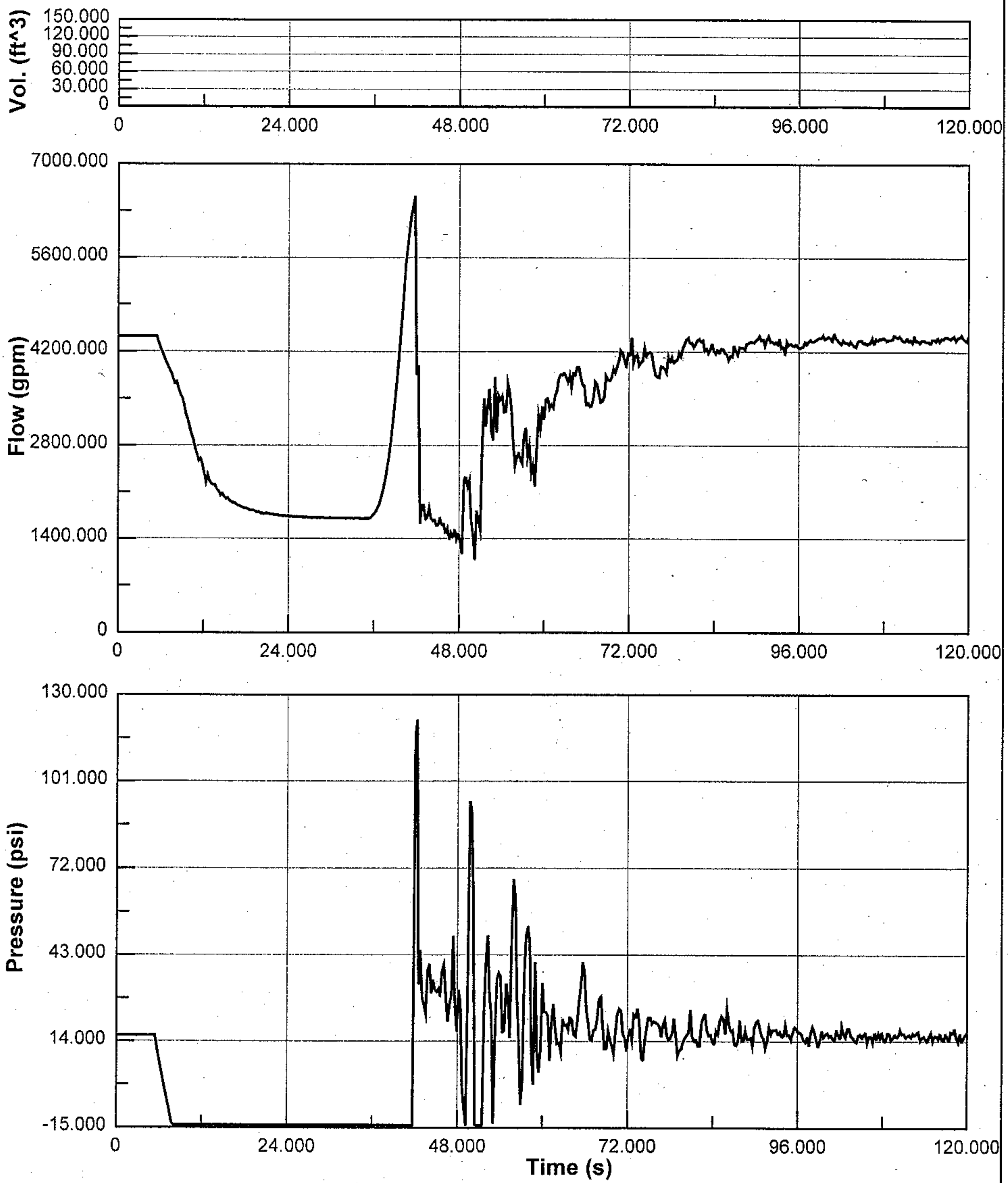
FIGURES



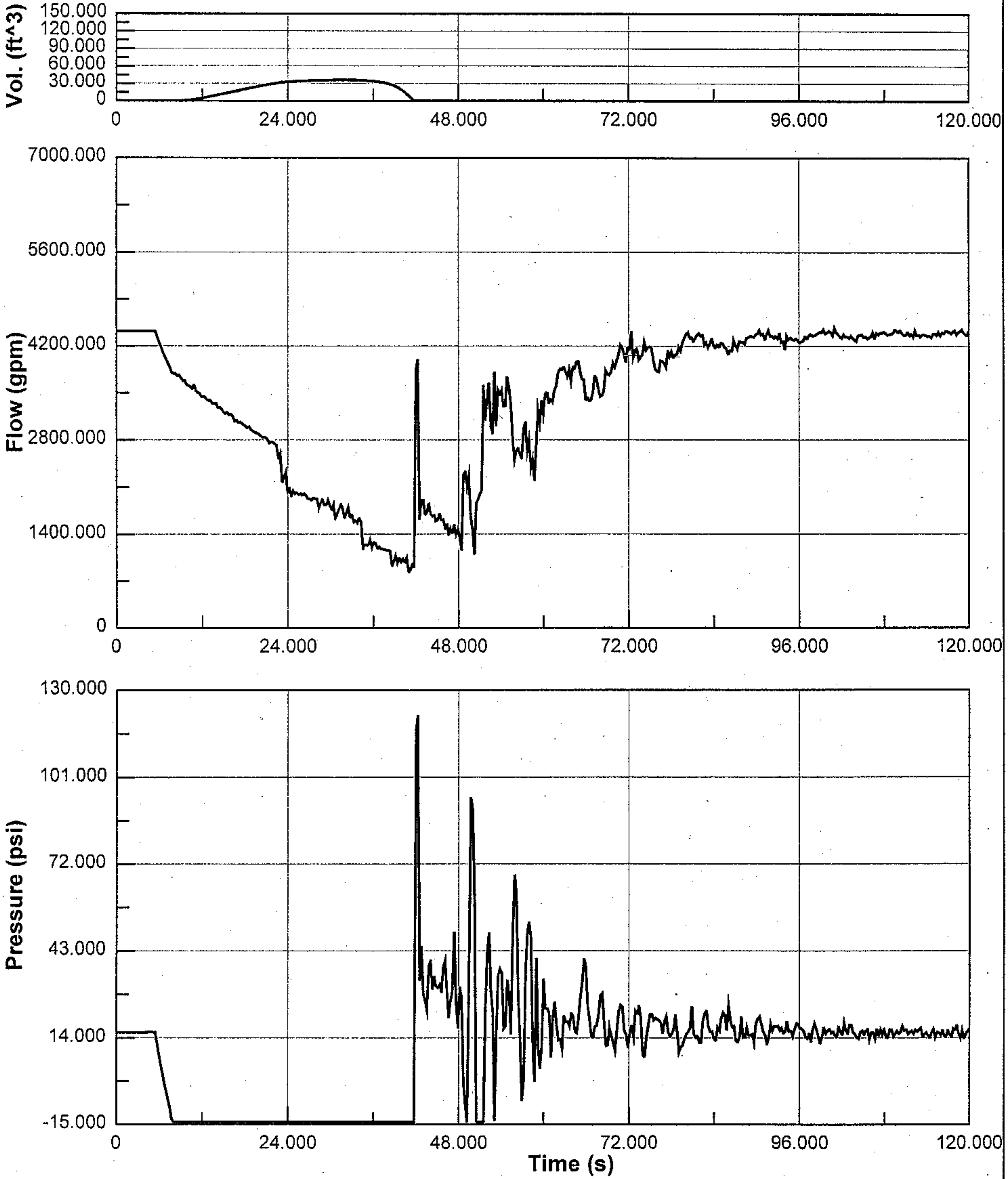
	TM#3 - Surge Analysis	June 2006	PS 35 without Protection - Pressure Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #1	



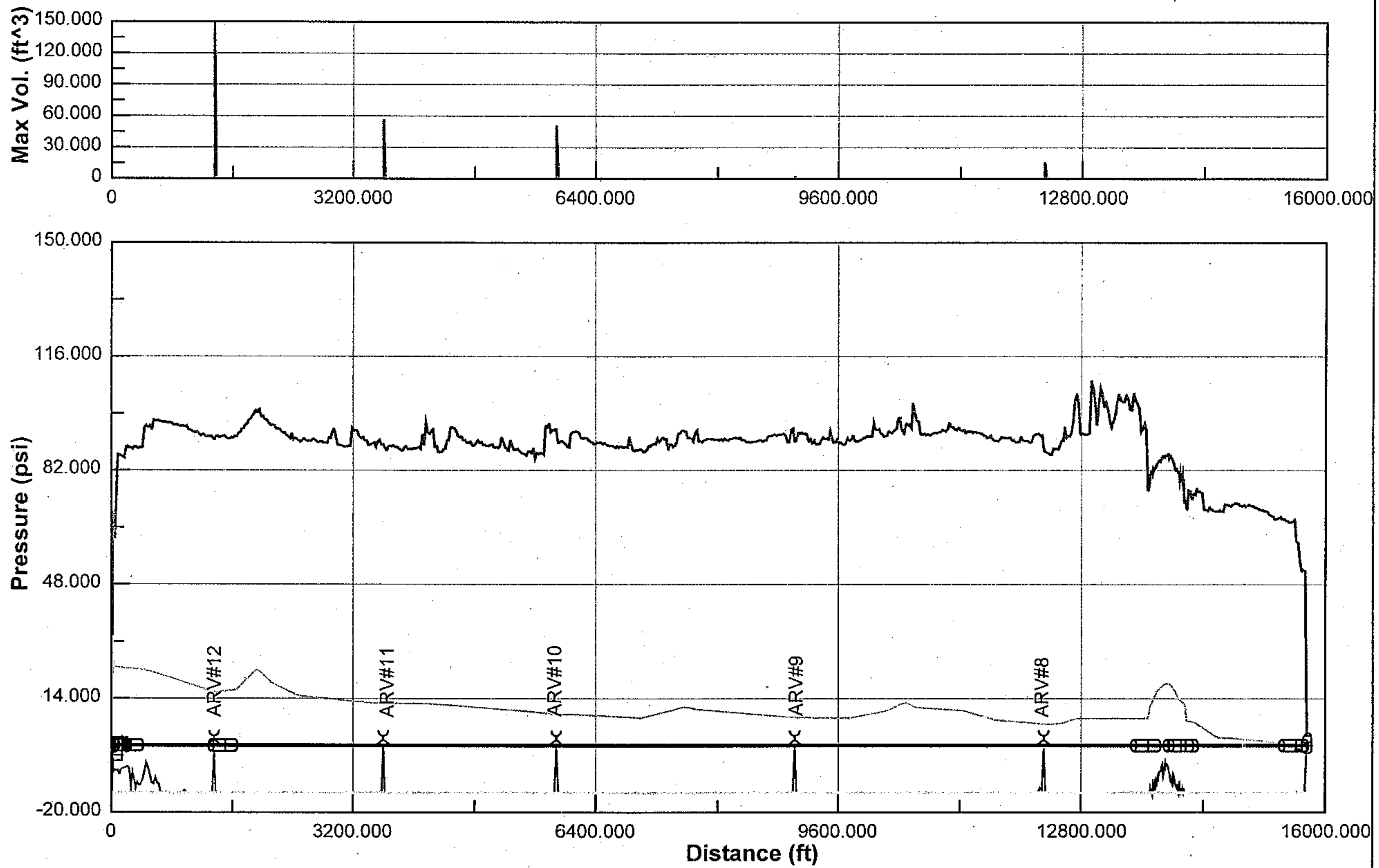
	TM#3 - Surge Analysis	June 2006	PS 35 without Protection - Head Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #2	



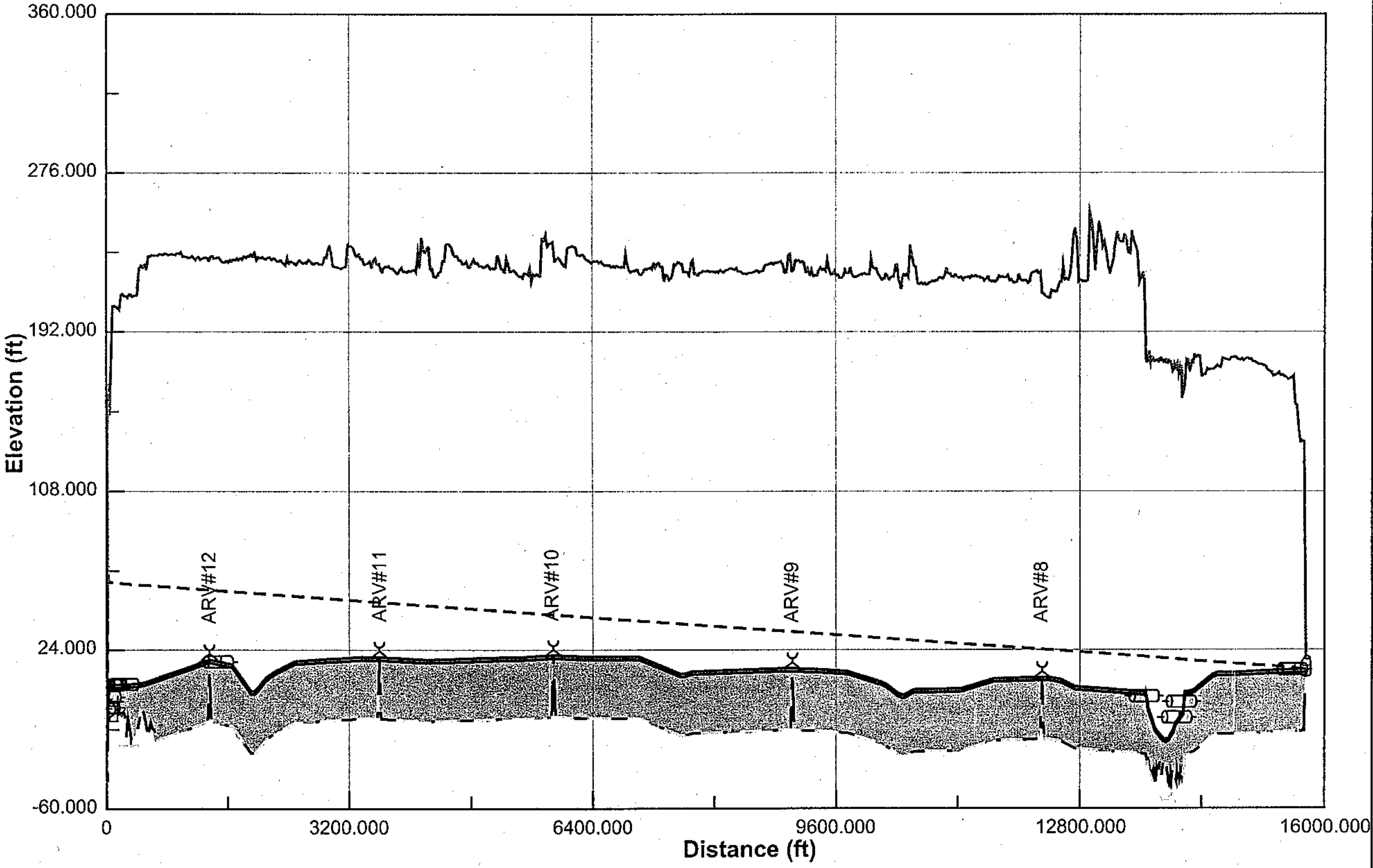
	TM#3 - Surge Analysis	June 2006	PS 35 without Protection - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
	www.haestad.com METHODS	Figure #3	



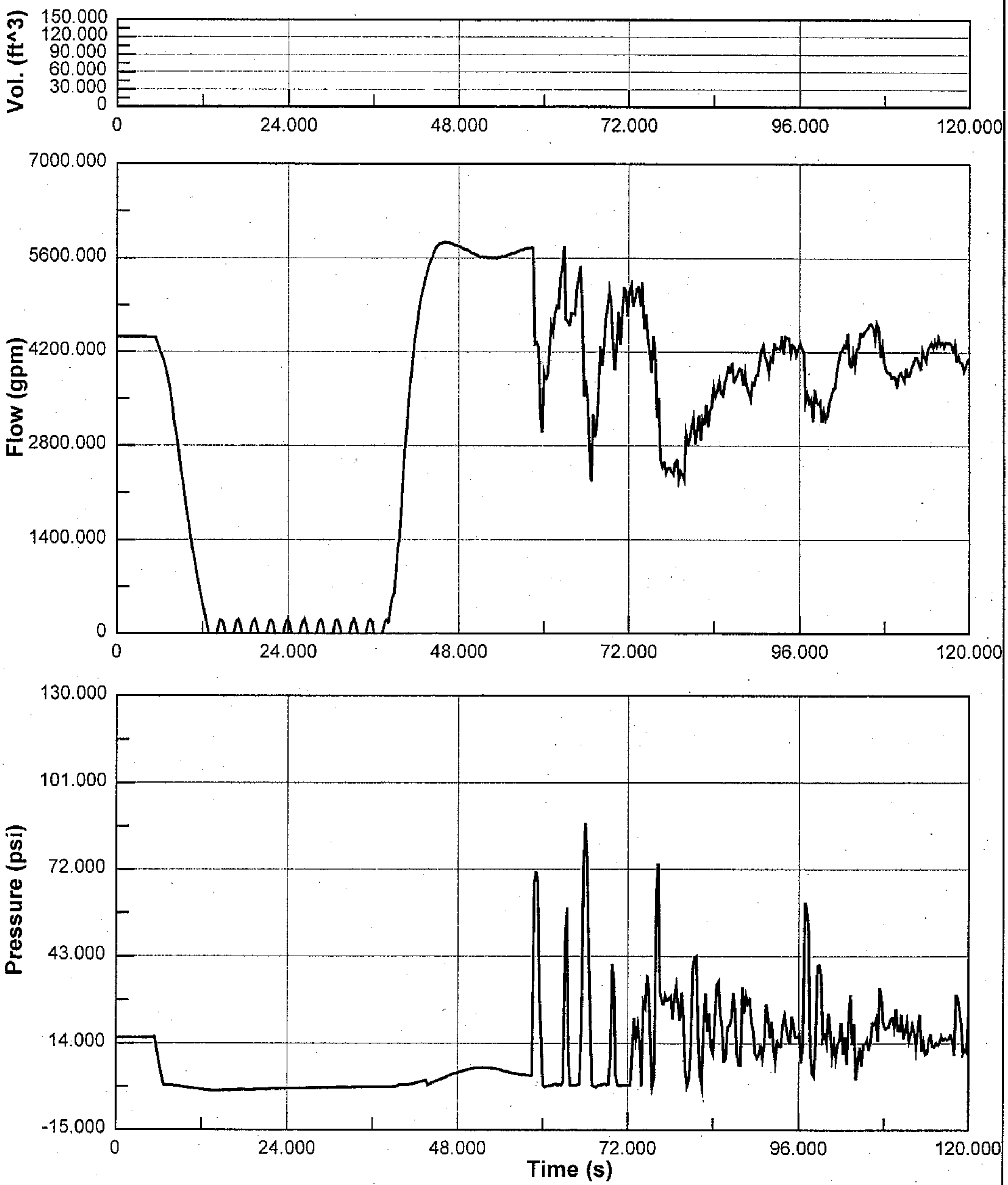
	TM#3 - Surge Analysis	June 2006	PS 35 without Protection - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Downstream)
	www.haestad.com METHODS	Figure #4	



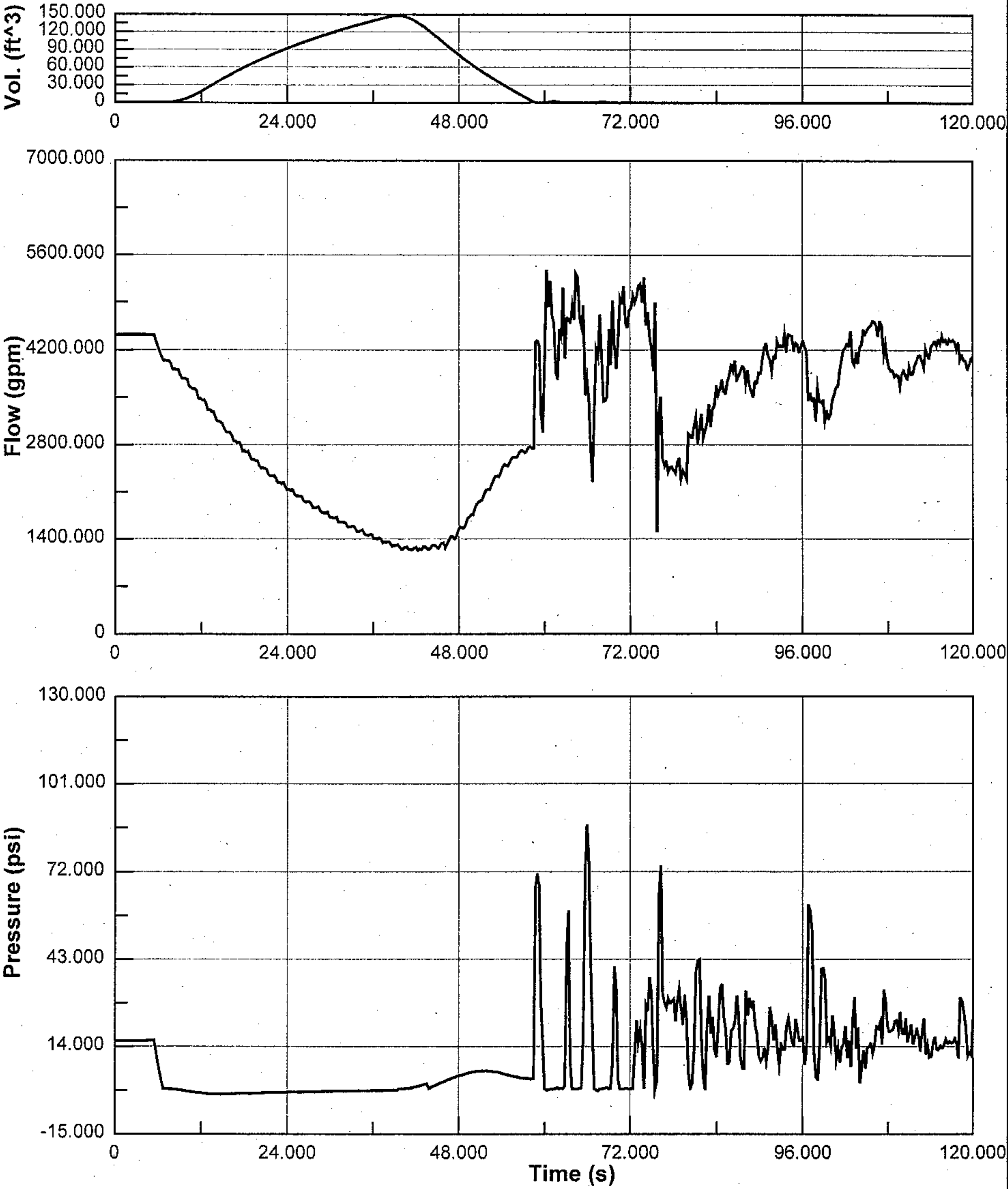
TM#3 - Surge Analysis	June 2006	PS 35 with 2" Combination Air/Vacuum Valves - Pressure Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #5	



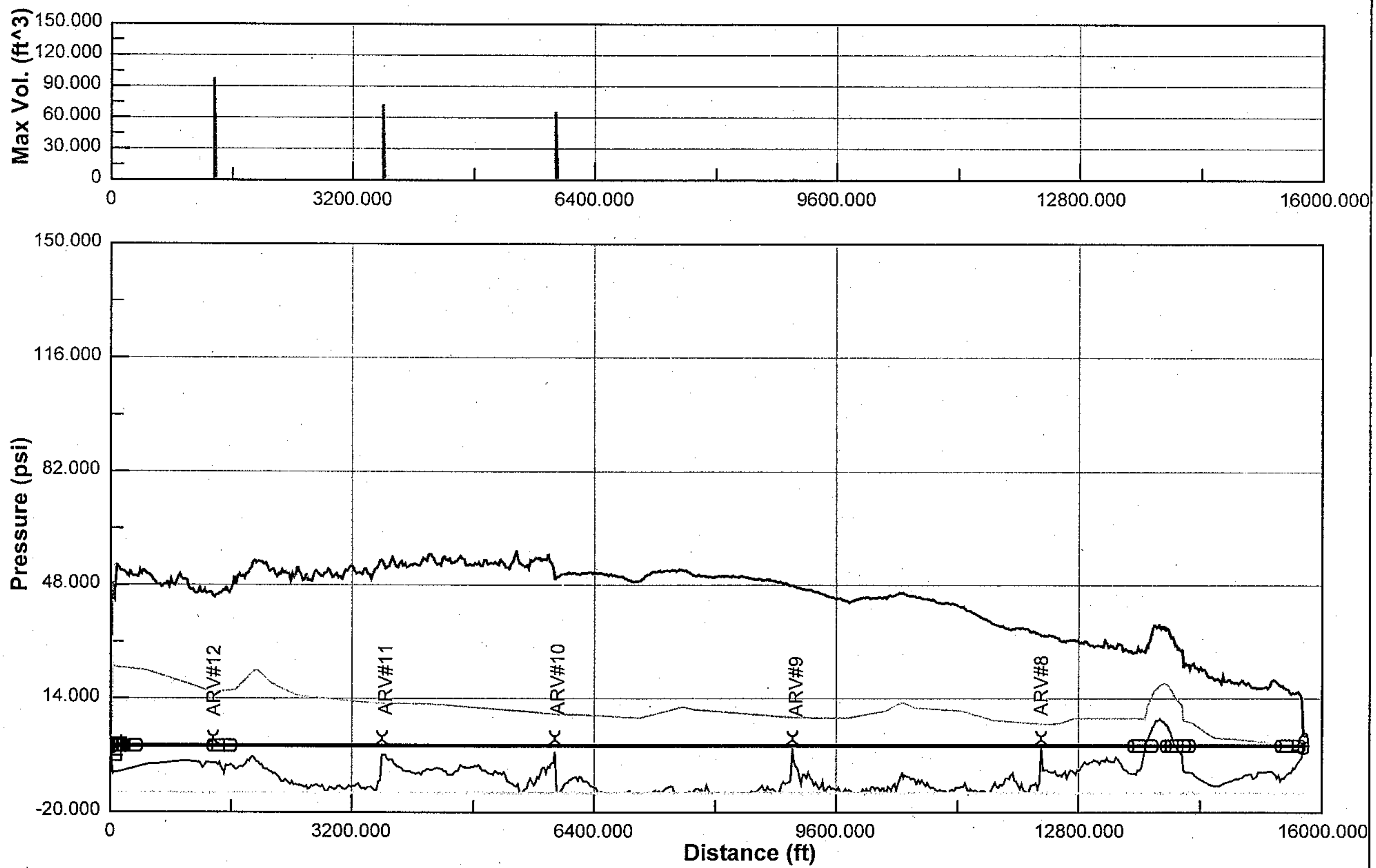
	TM#3 - Surge Analysis	June 2006	PS 35 with 2" Combination Air/Vacuum Valves - Head Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #6	



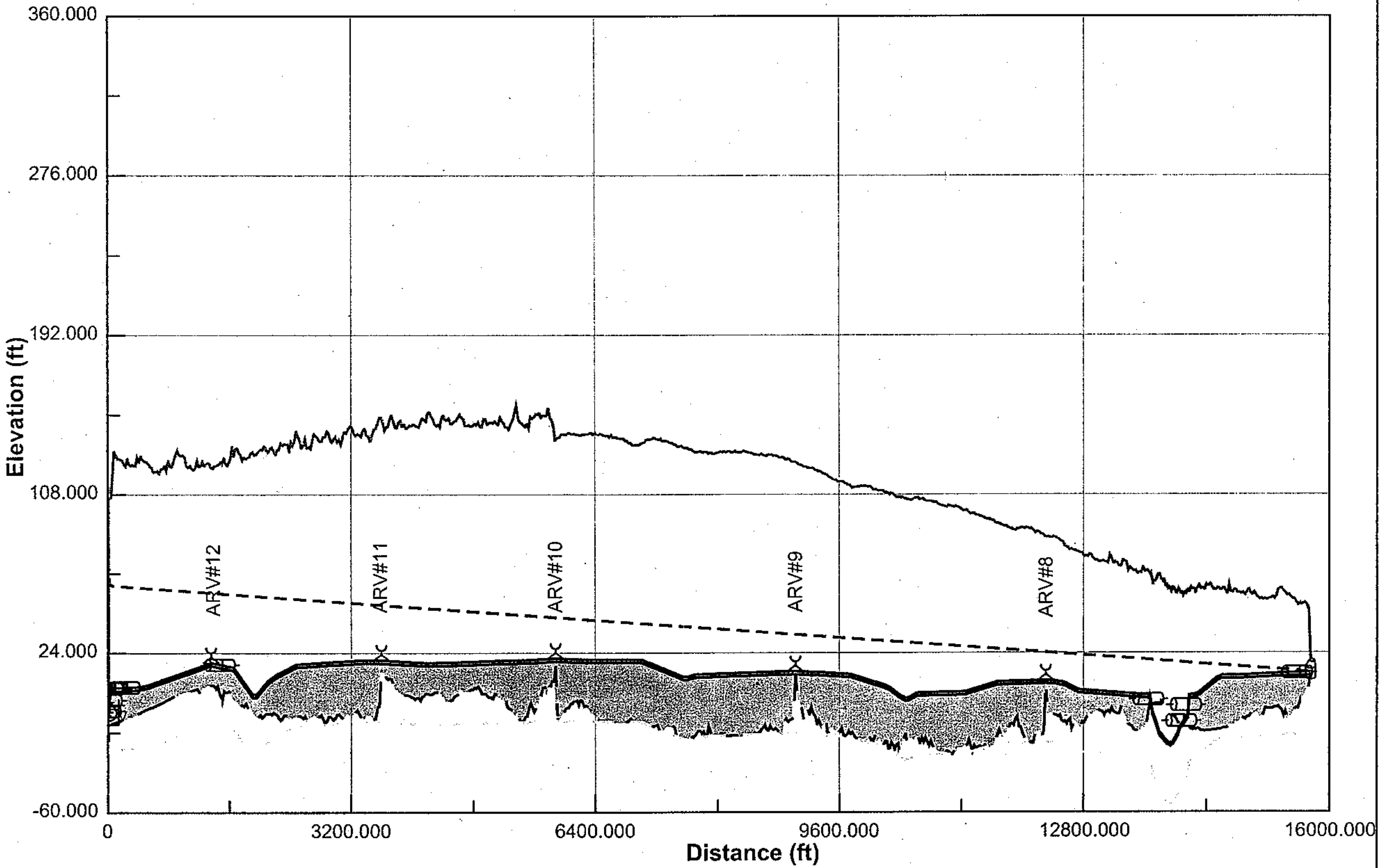
TM#3 - Surge Analysis	June 2006	PS 35 with 2" Combination Air/Vacuum Valves - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
www.haestad.com METHODS	Figure #7	



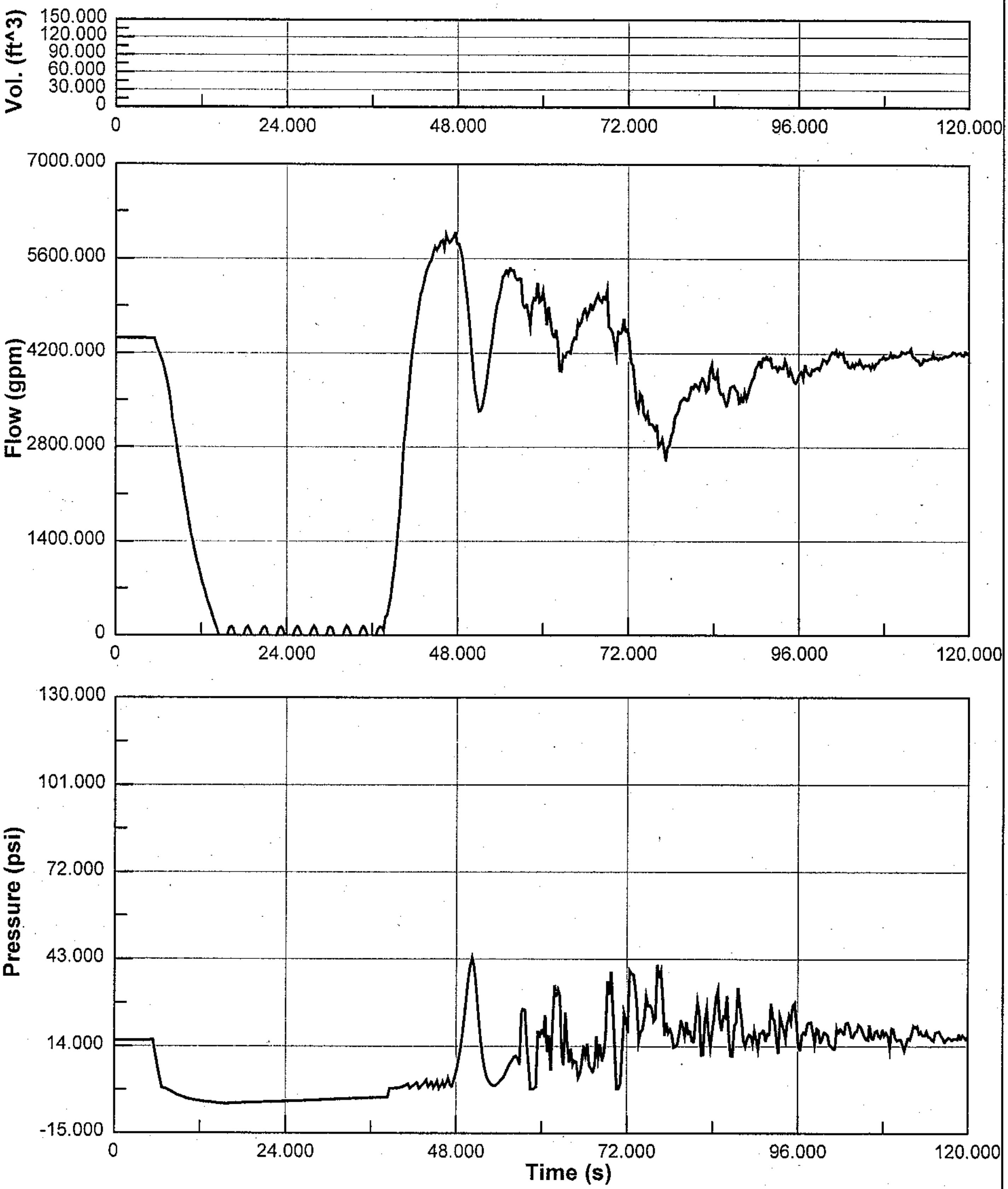
	TM#3 - Surge Analysis	June 2006	PS 35 with 2" Combination Air/Vacuum Valves - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Downstream)
	www.haestad.com METHODS	Figure #8	



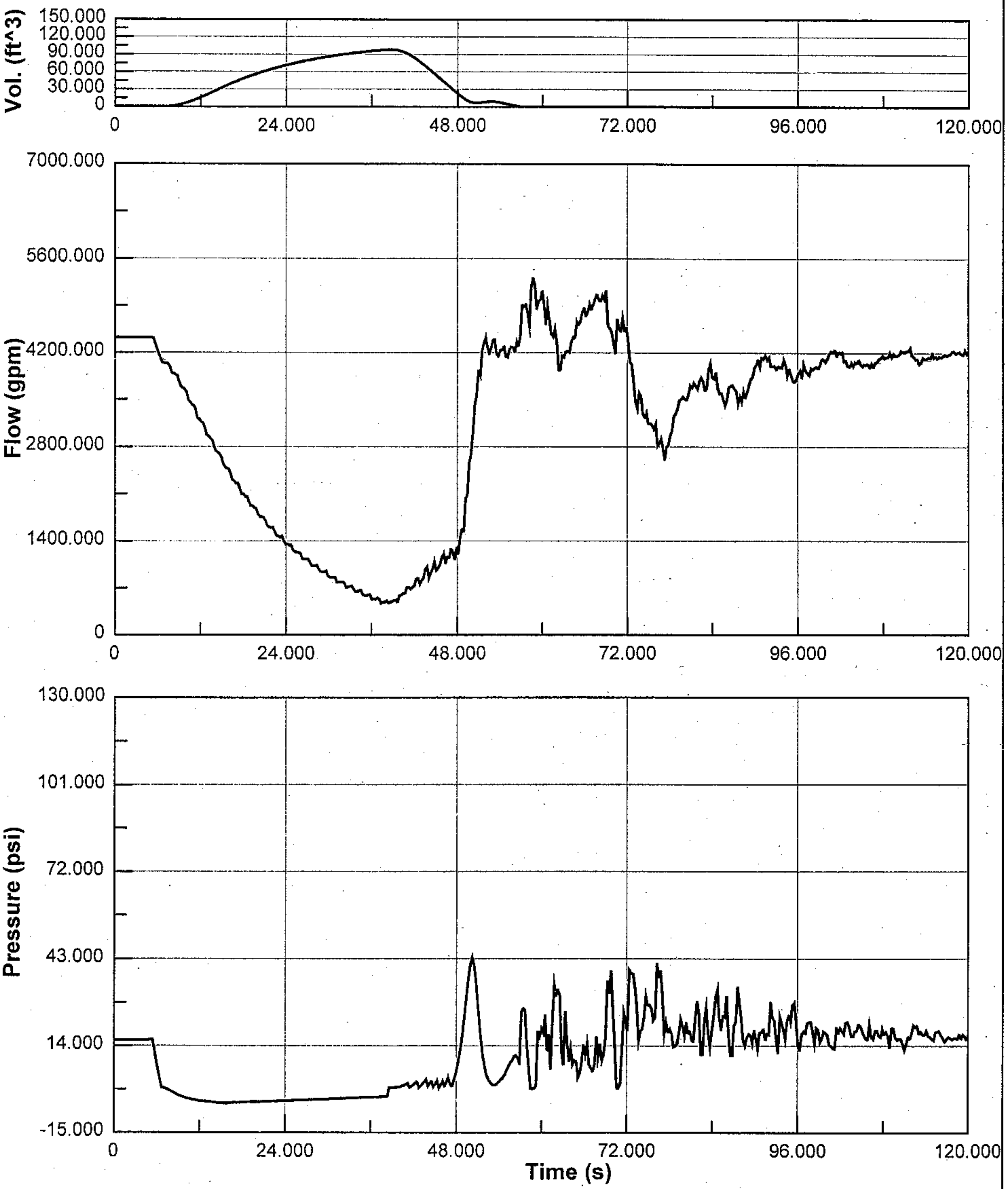
	TM#3 - Surge Analysis	June 2006	PS 35 with 1" Combination Air/Vacuum Valves - Pressure Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #9	



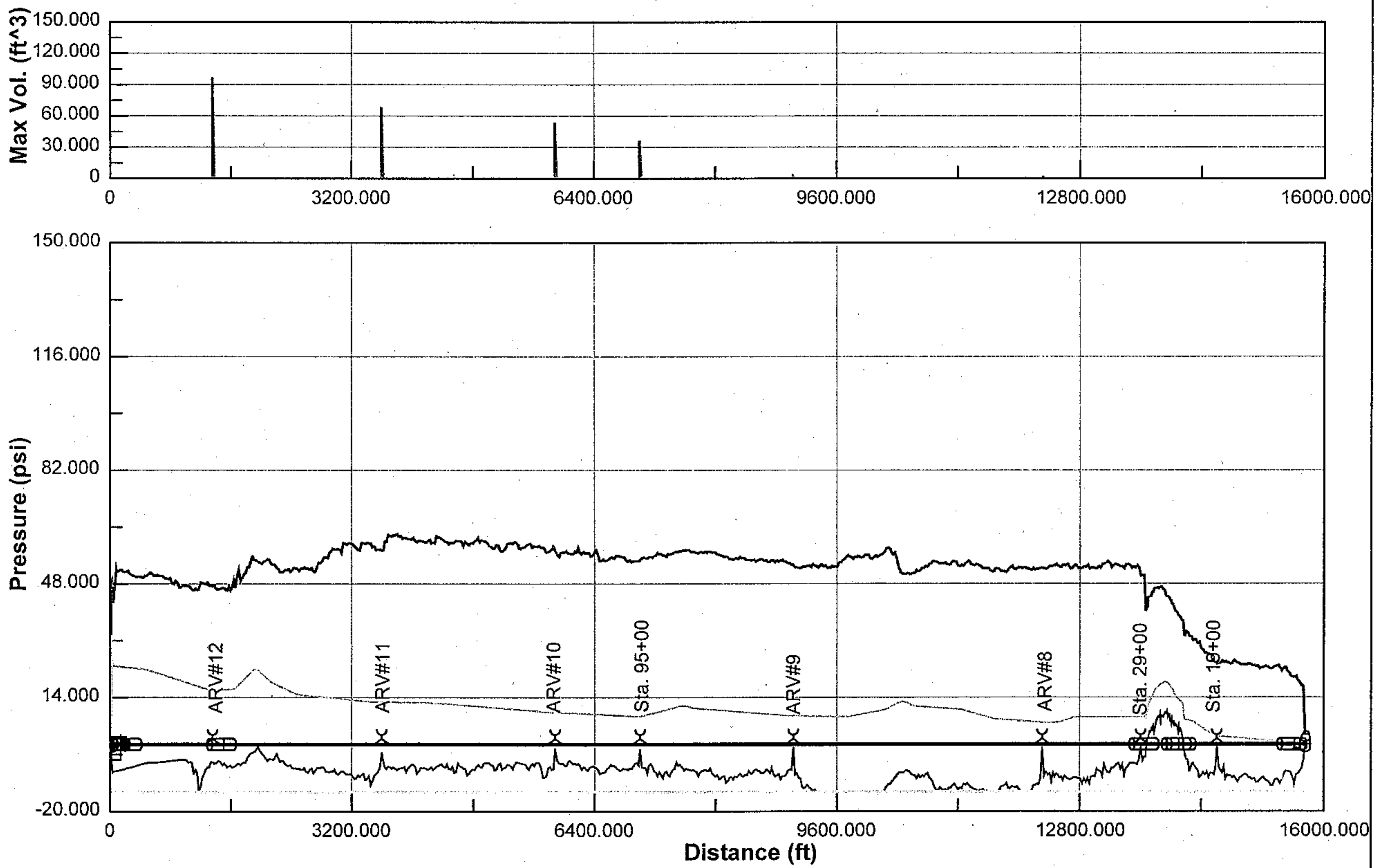
	TM#3 - Surge Analysis	June 2006	PS 35 with 1" Combination Air/Vacuum Valves - Head Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #10	



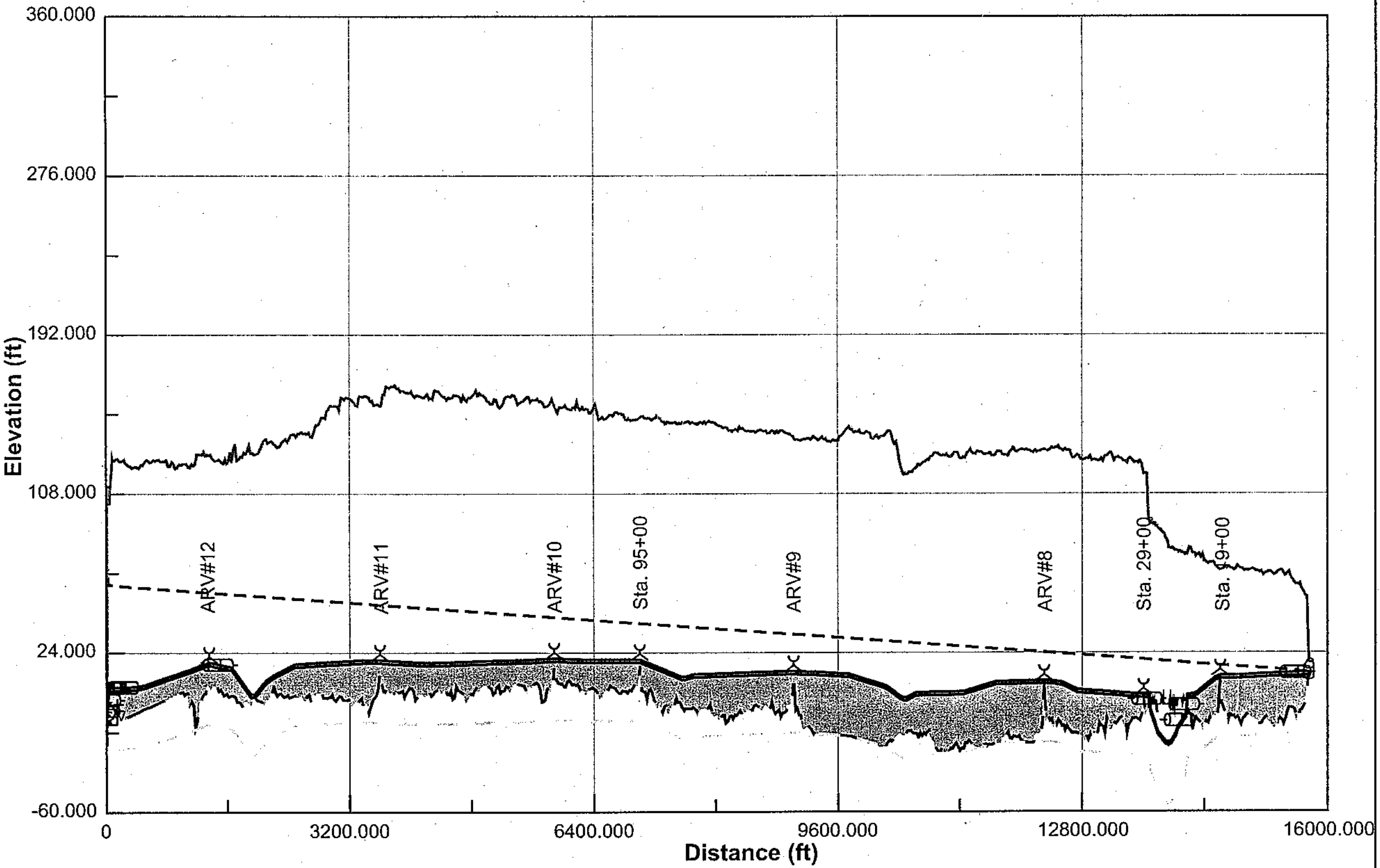
	TM#3 - Surge Analysis	June 2006	PS 35 with 1" Combination Air/Vacuum Valves - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
	www.haestad.com METHODS	Figure #11	



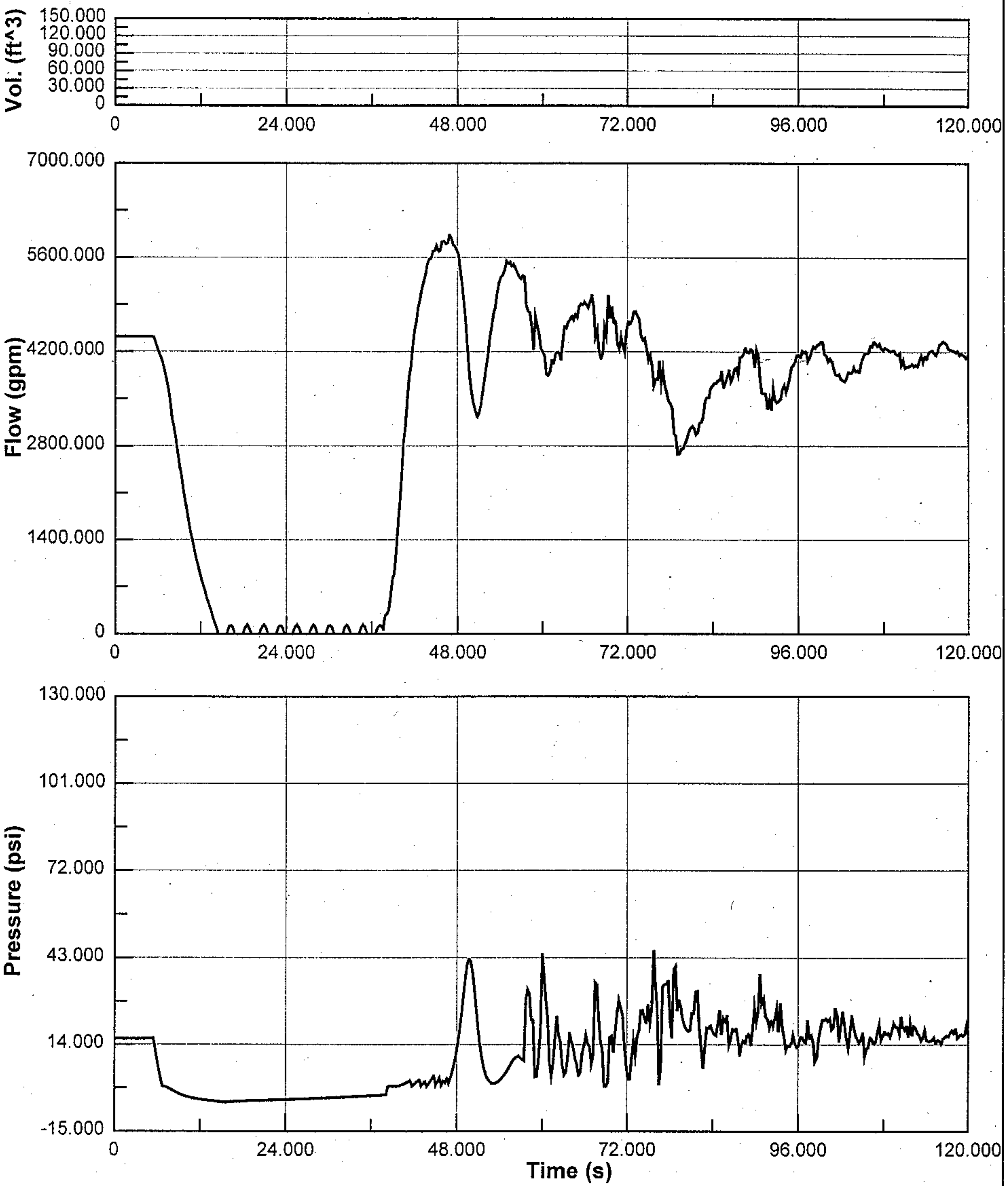
	TM#3 - Surge Analysis	June 2006	PS 35 with 1" Combination Air/Vacuum Valves - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Downstream)
	www.haestad.methods.com	Figure #12	



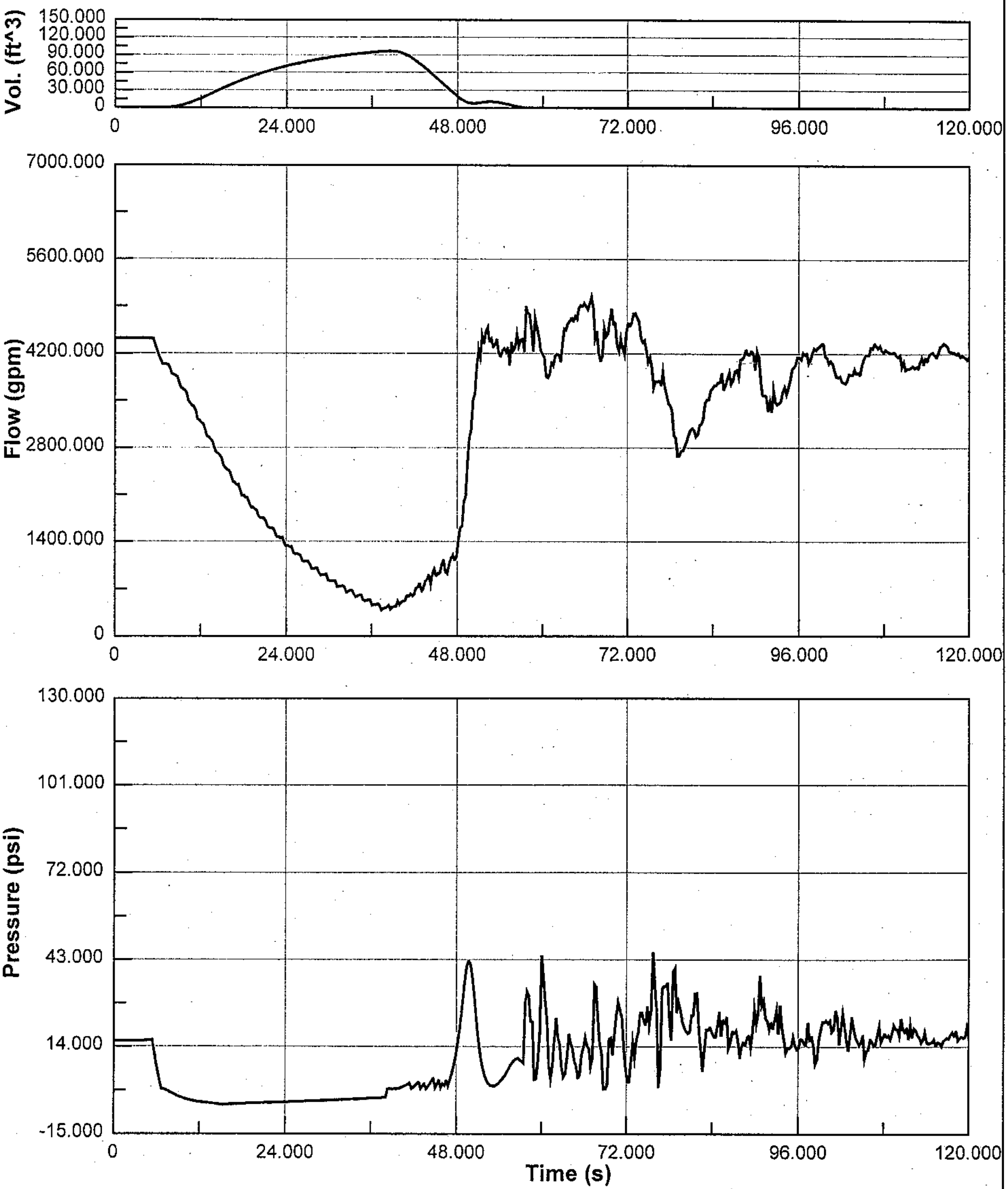
TM#3 - Surge Analysis	June 2006	PS 35 with Additional Valves - Pressure Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #13	



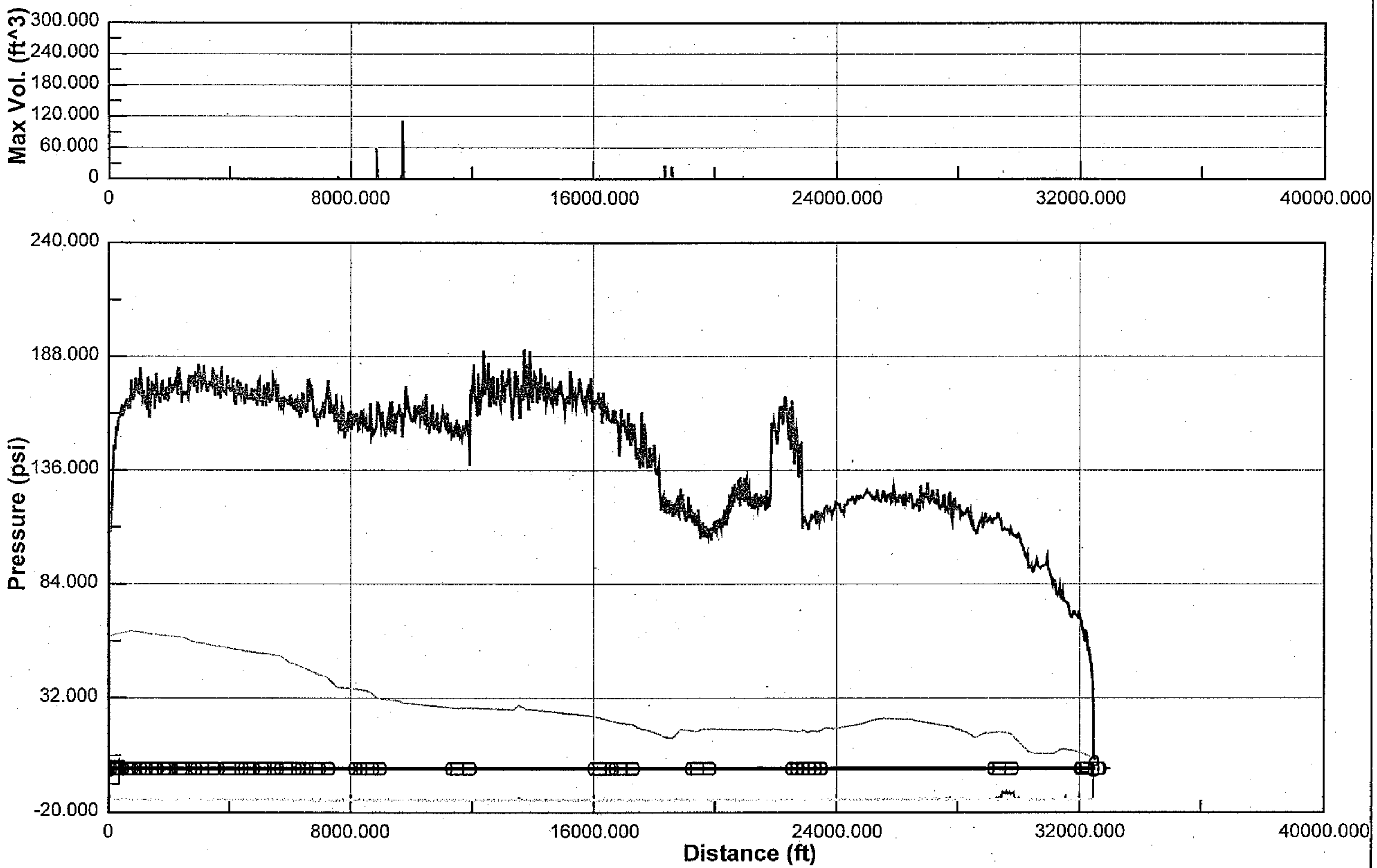
	TM#3 - Surge Analysis	June 2006	PS 35 with Additional Valves - Head Envelope w/Pump Failure and Restart after 30 sec
		Figure #14	



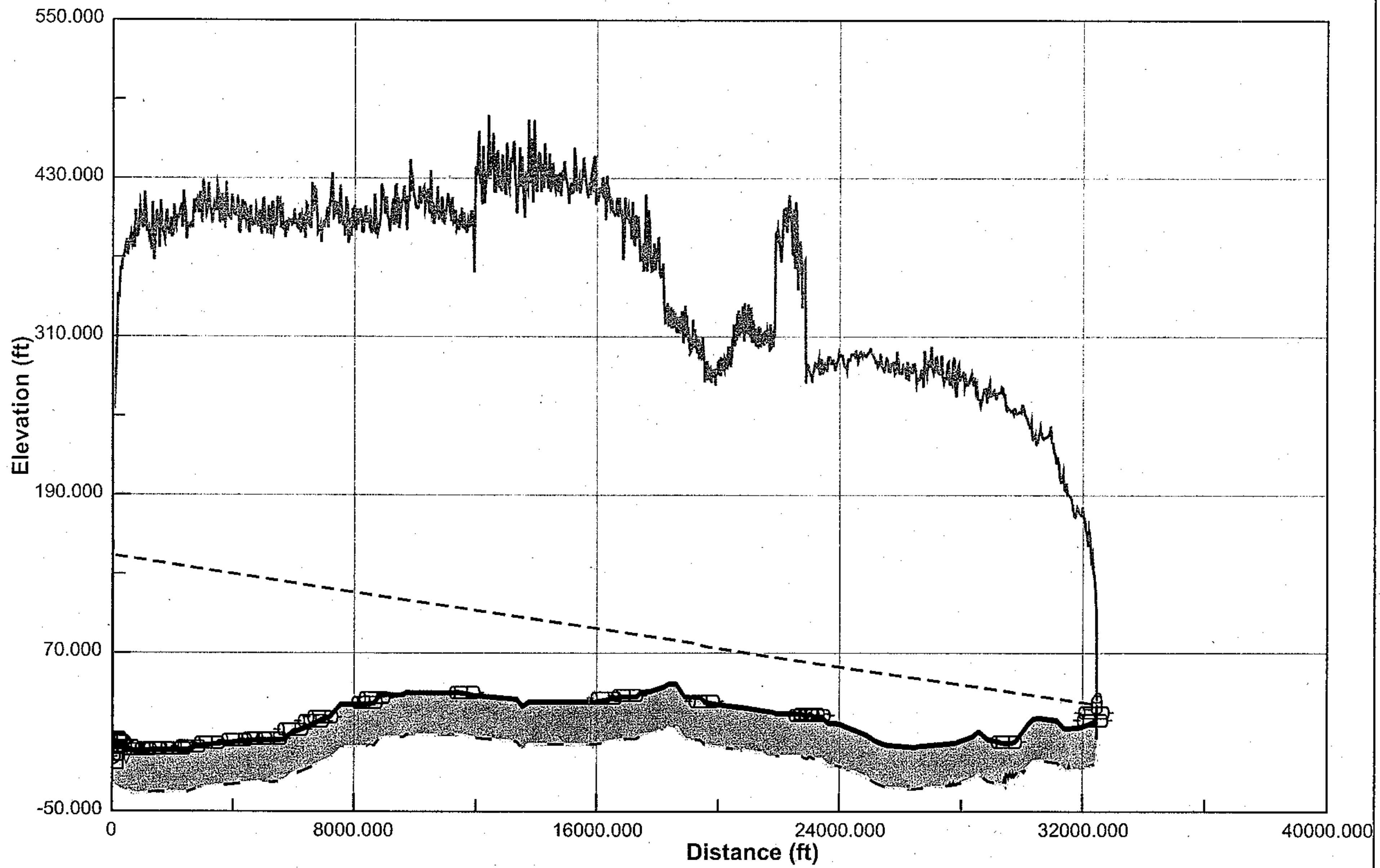
	TM#3 - Surge Analysis	June 2006	PS 35 with Additional Valves - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
	www.haestad.com METHODS	Figure #15	



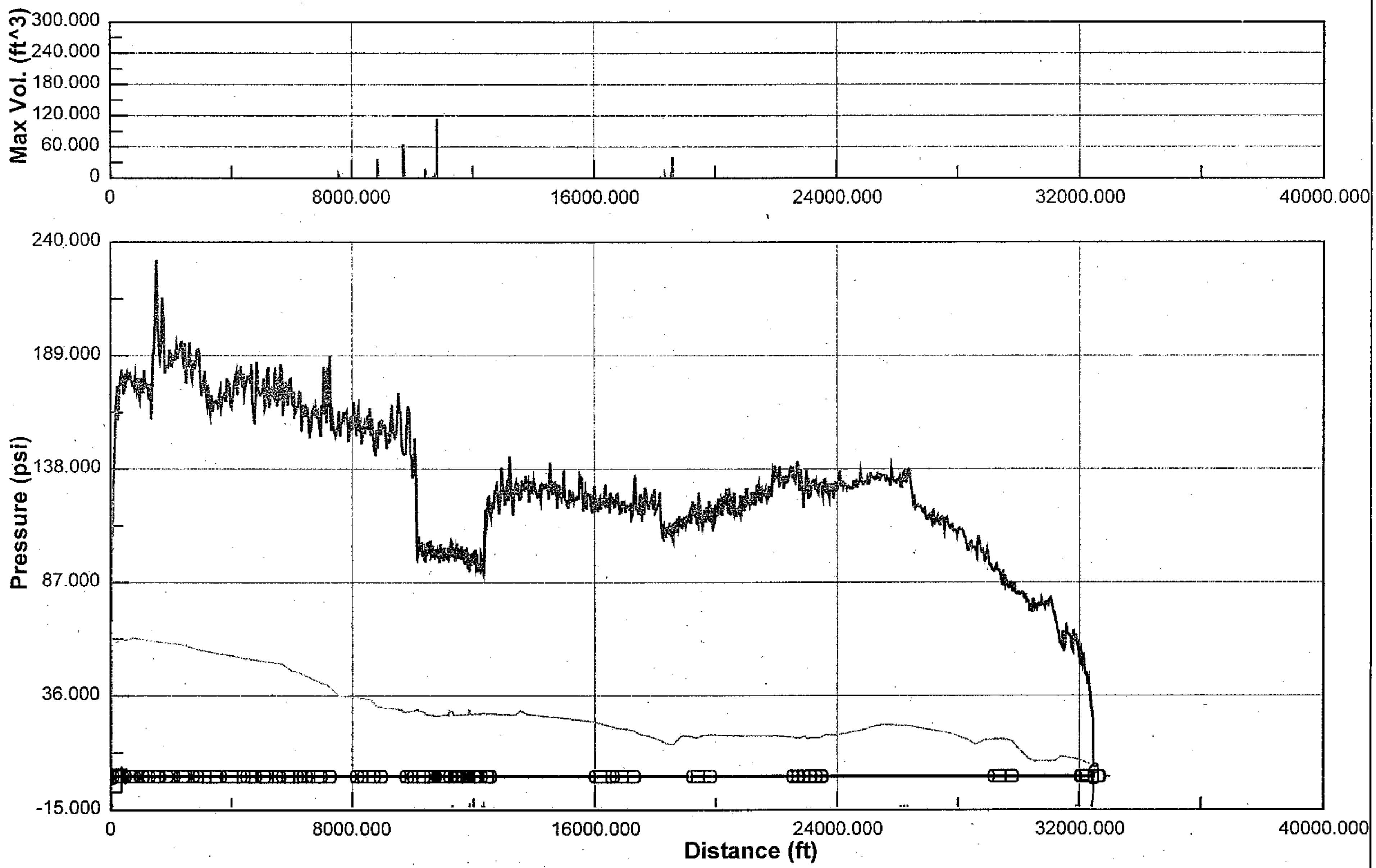
	TM#3 - Surge Analysis	June 2006	PS 35 with Additional Valves - ARV#12 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Downstream)
	www.haestad.com METHODS	Figure #16	



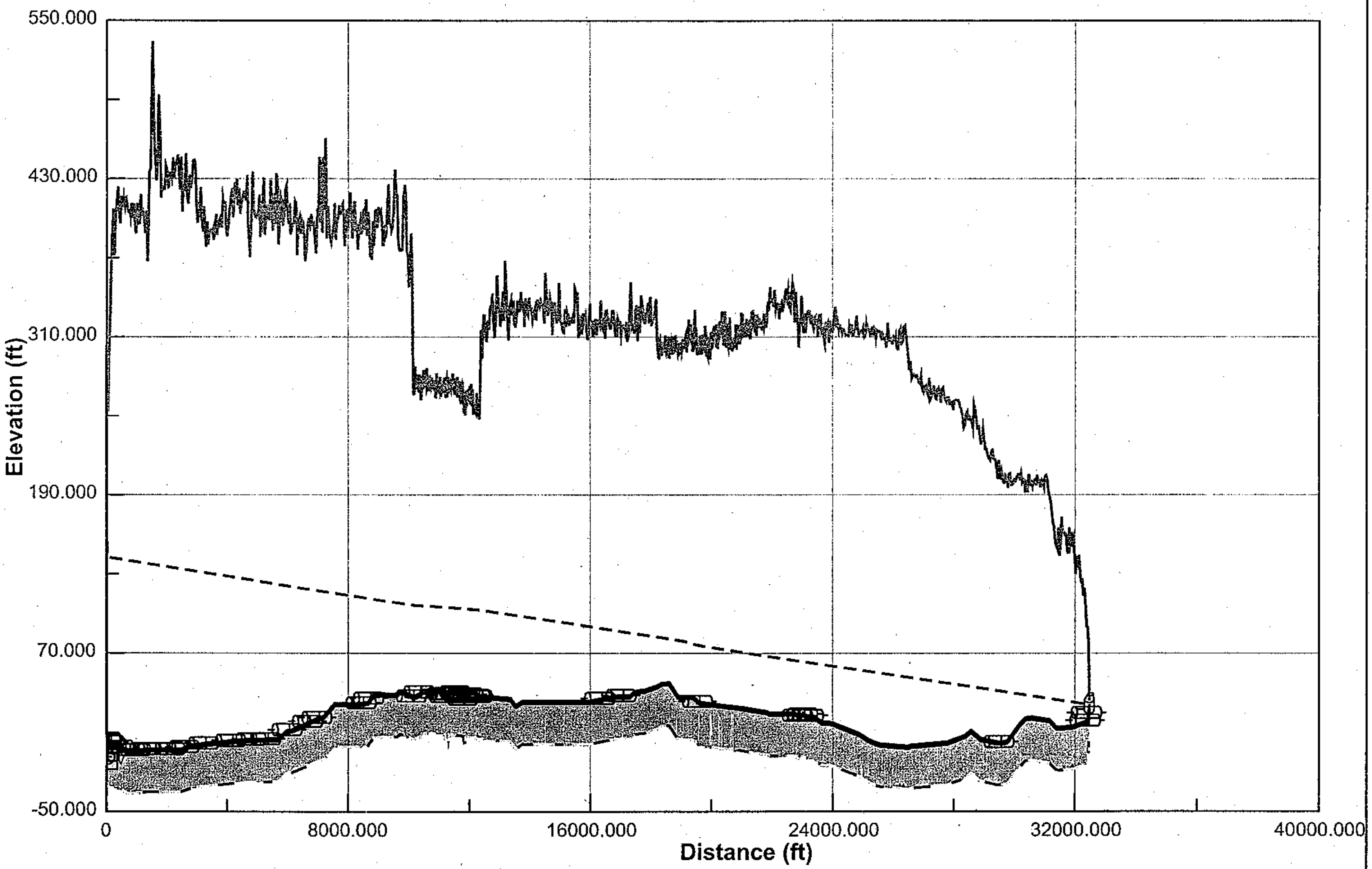
TM#3 - Surge Analysis	June 2006	PS 34 Current System with No Protection - Pressure Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #17	



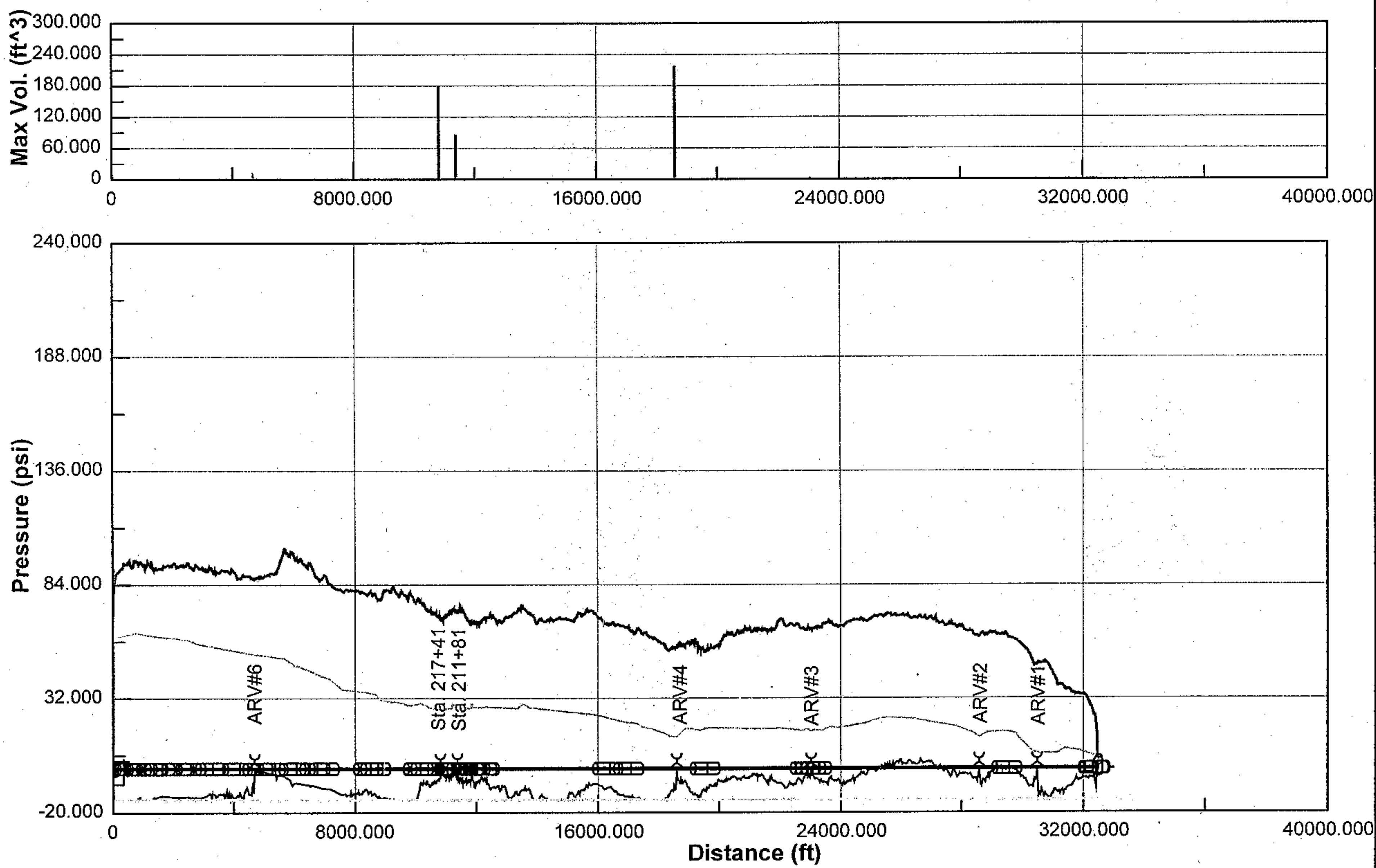
TM#3 - Surge Analysis	June 2006	PS 34 Current System with No Protection - Head Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #18	



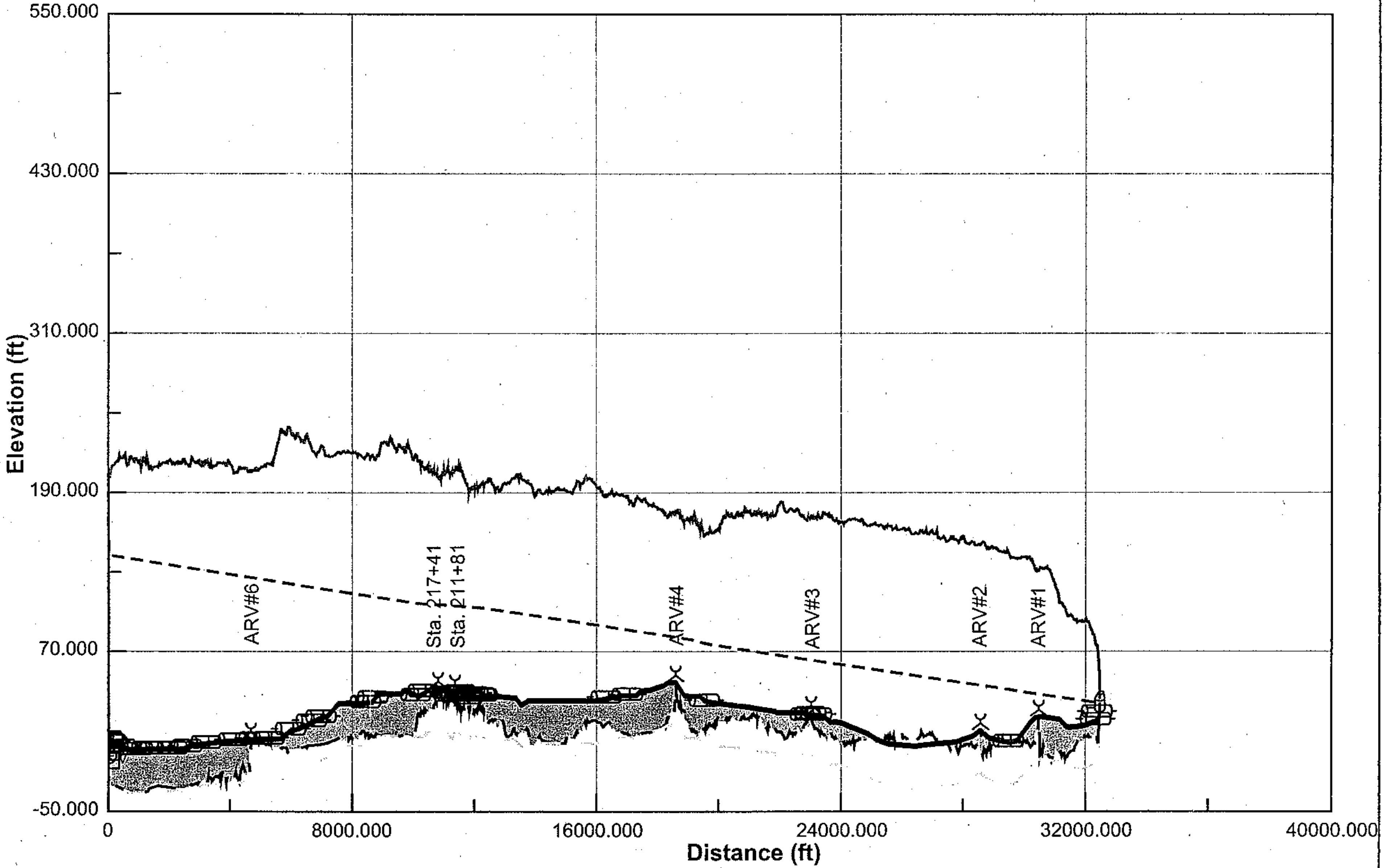
TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation without Protection - Pressure Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #19	



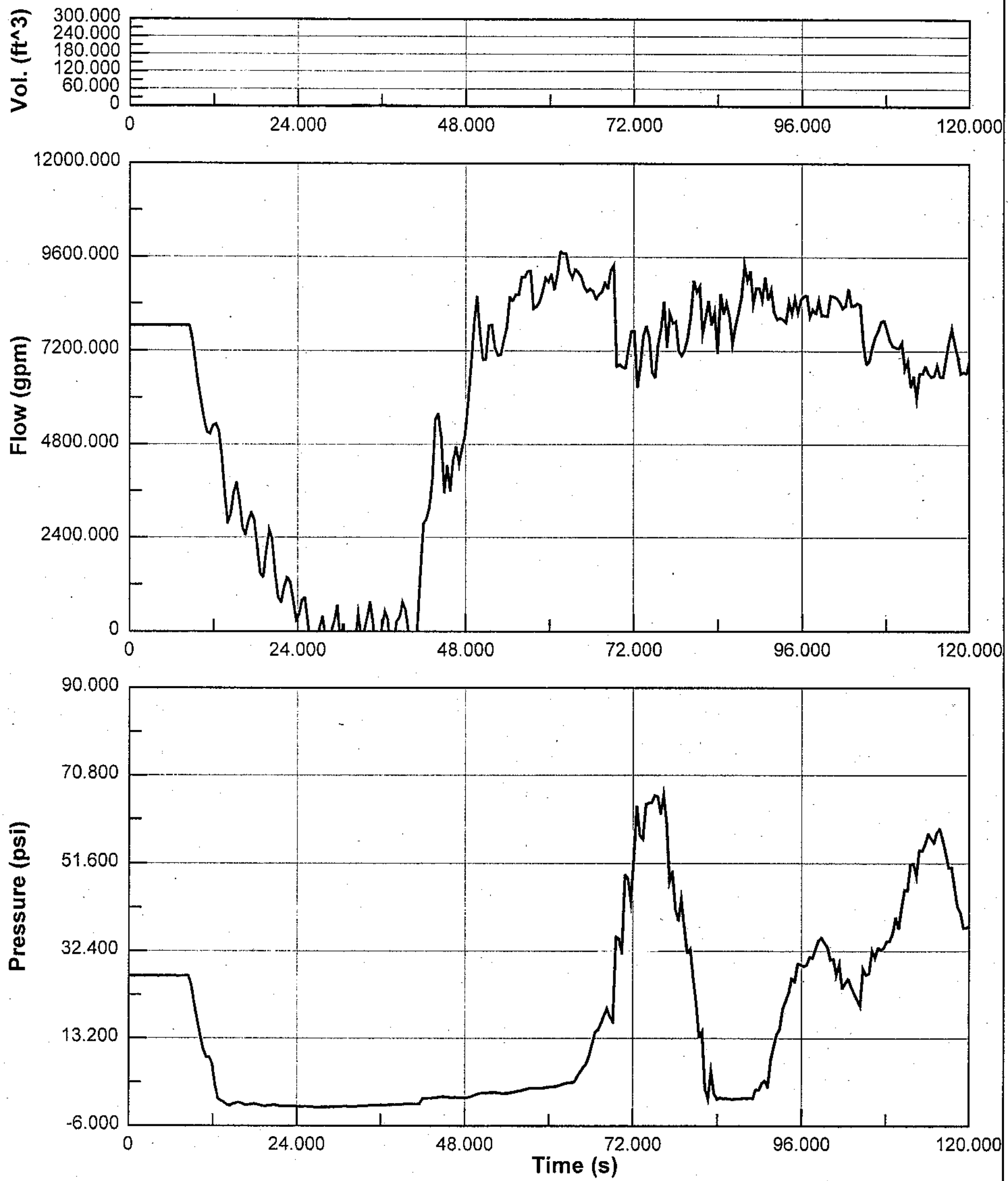
TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation without Protection - Head Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #20	



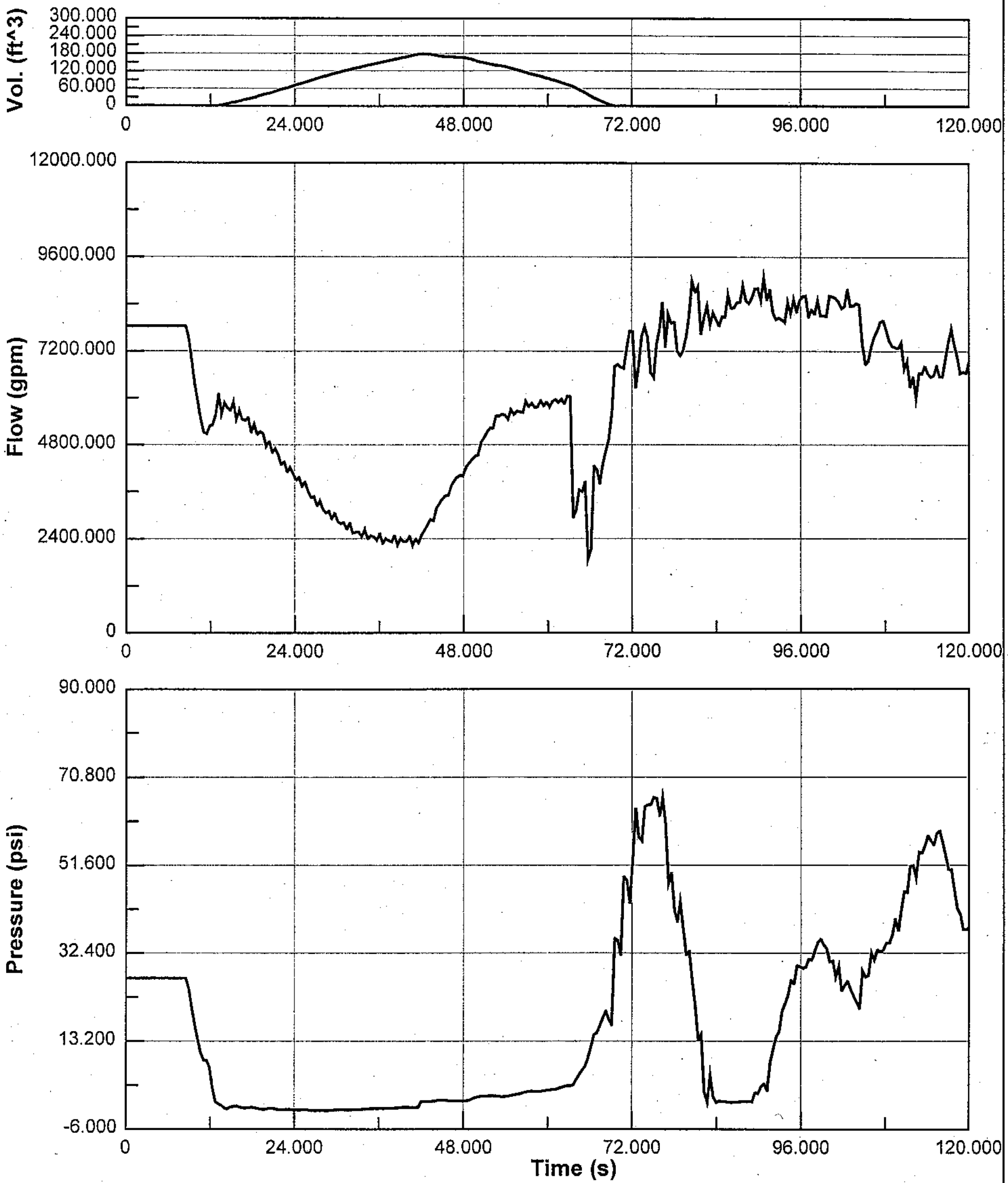
	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 2" Combination Air/Vacuum Valves - Pressure Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #21	



	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 2" Combination Air/Vacuum Valves - Head Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #22	



	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 2" Combination Air/Vacuum Valves - Sta. 217+41 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
	www.haestad.com METHODS	Figure #23	



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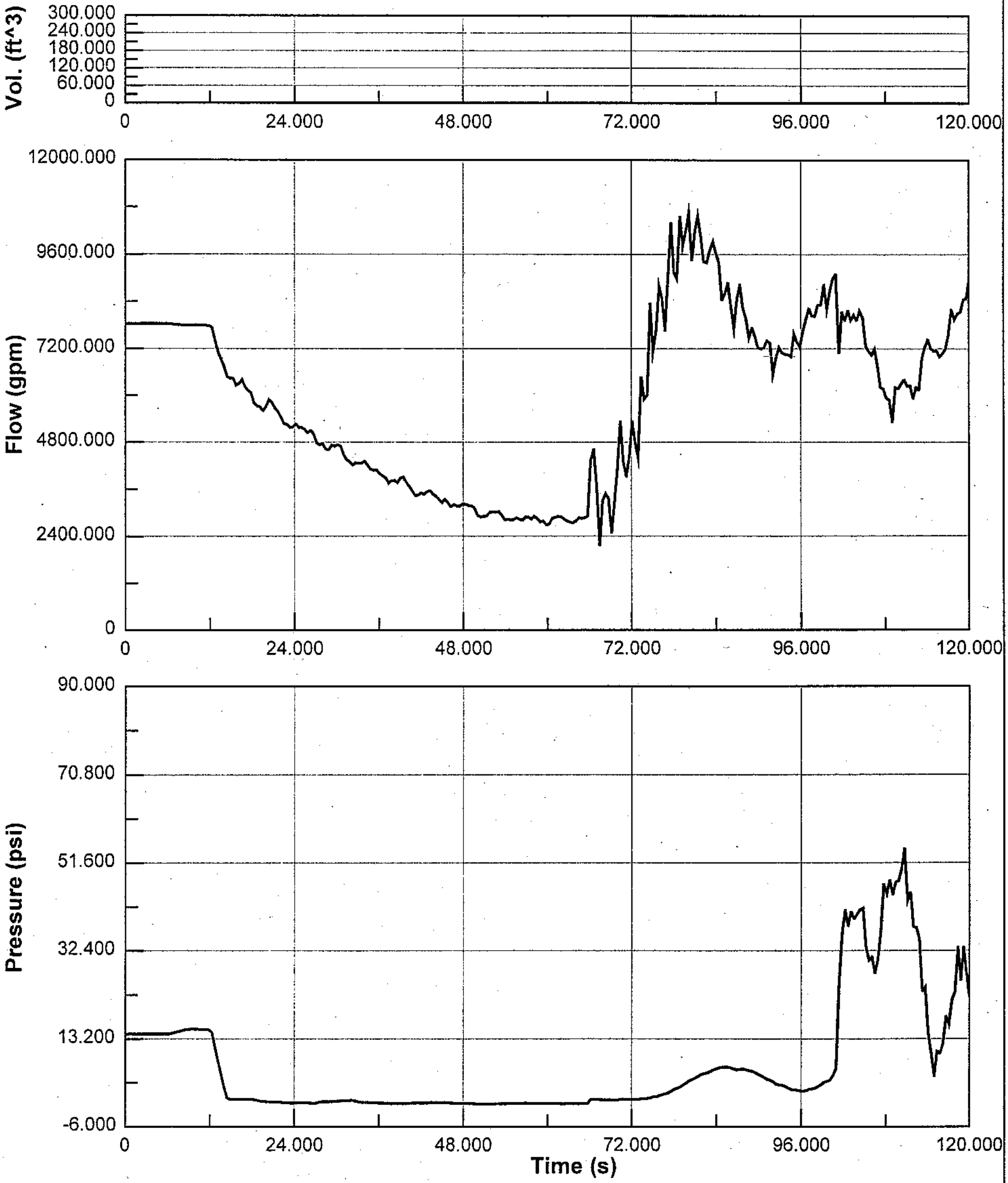
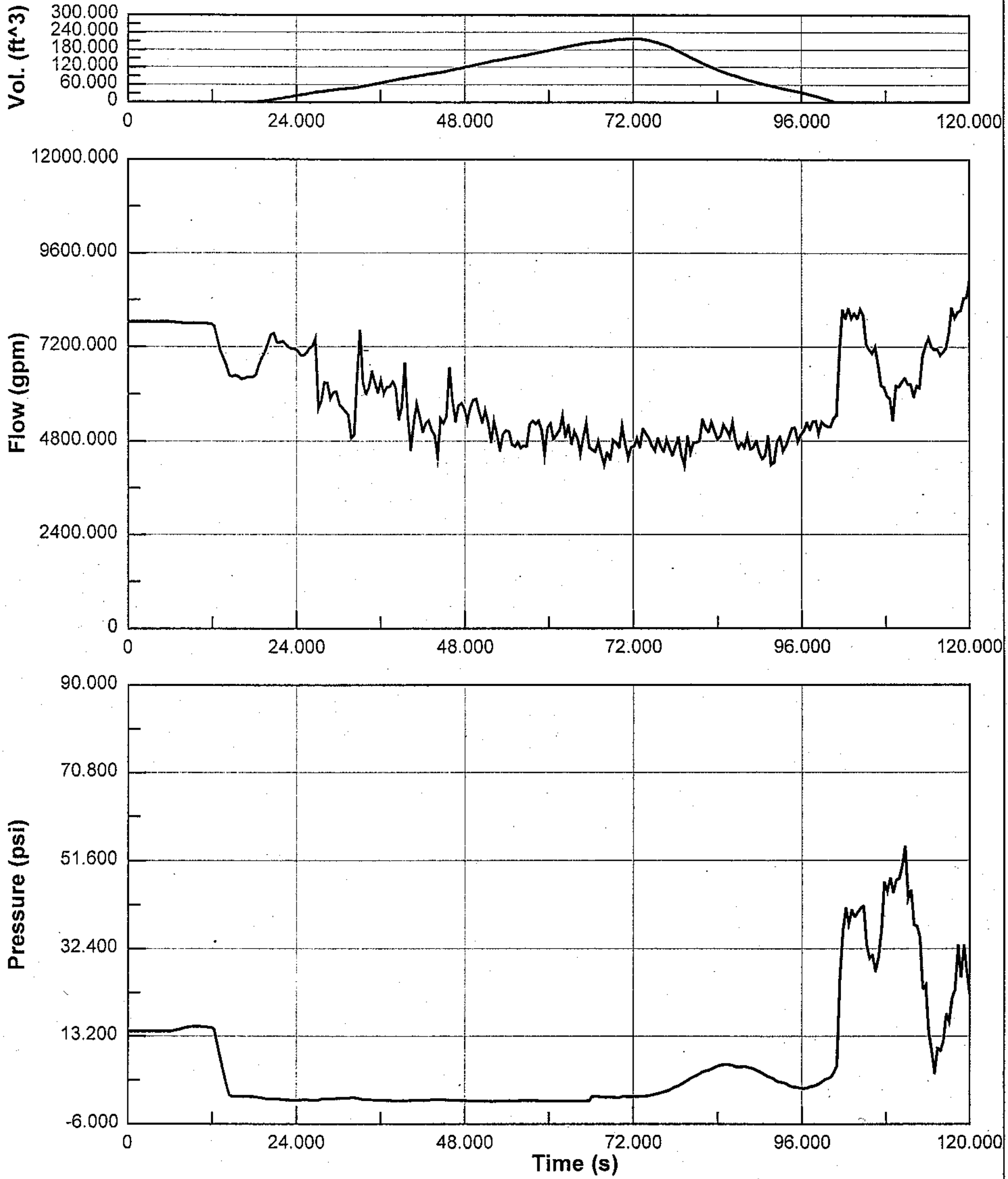
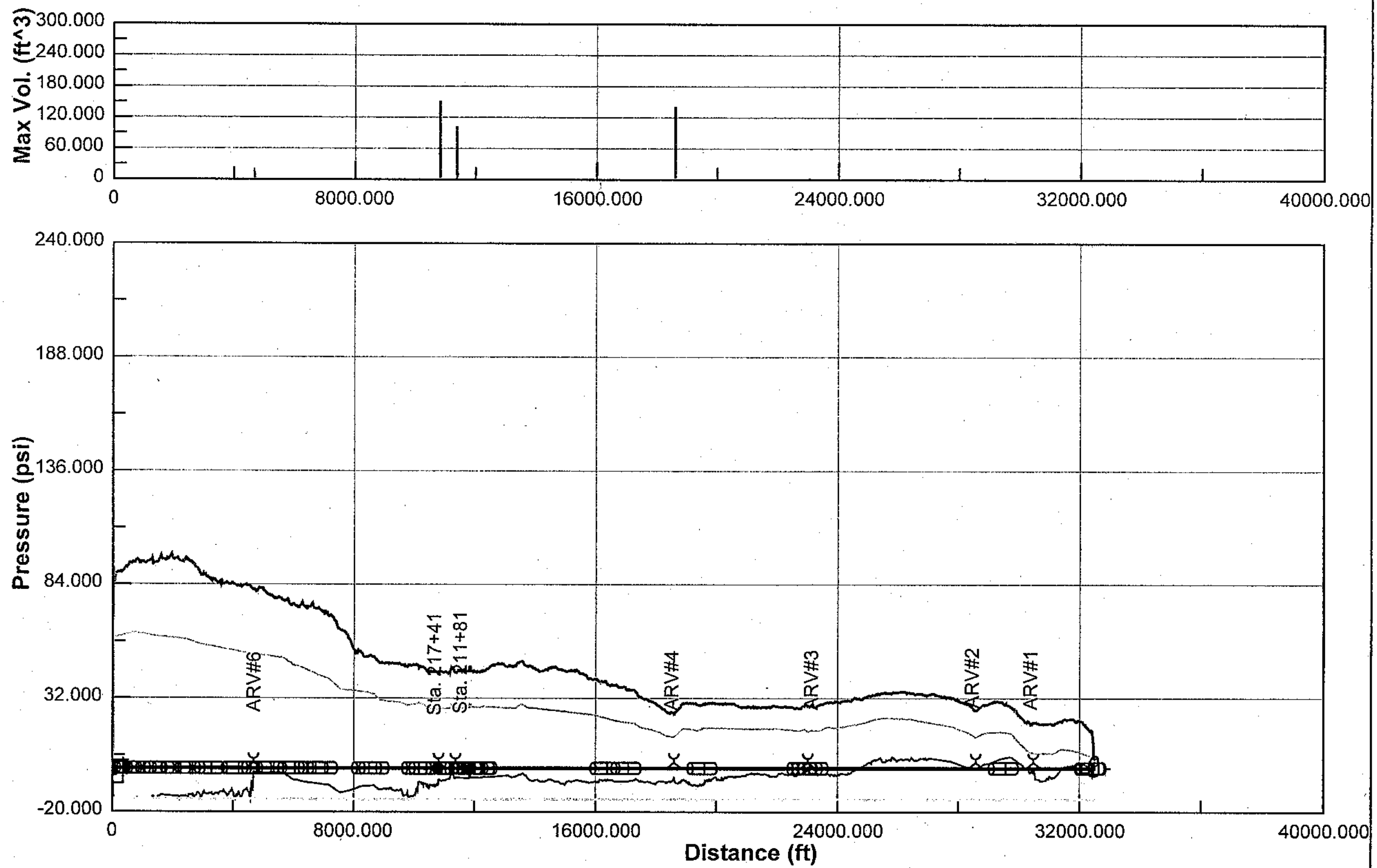
	www.haestad.com METHODS	Figure #24	



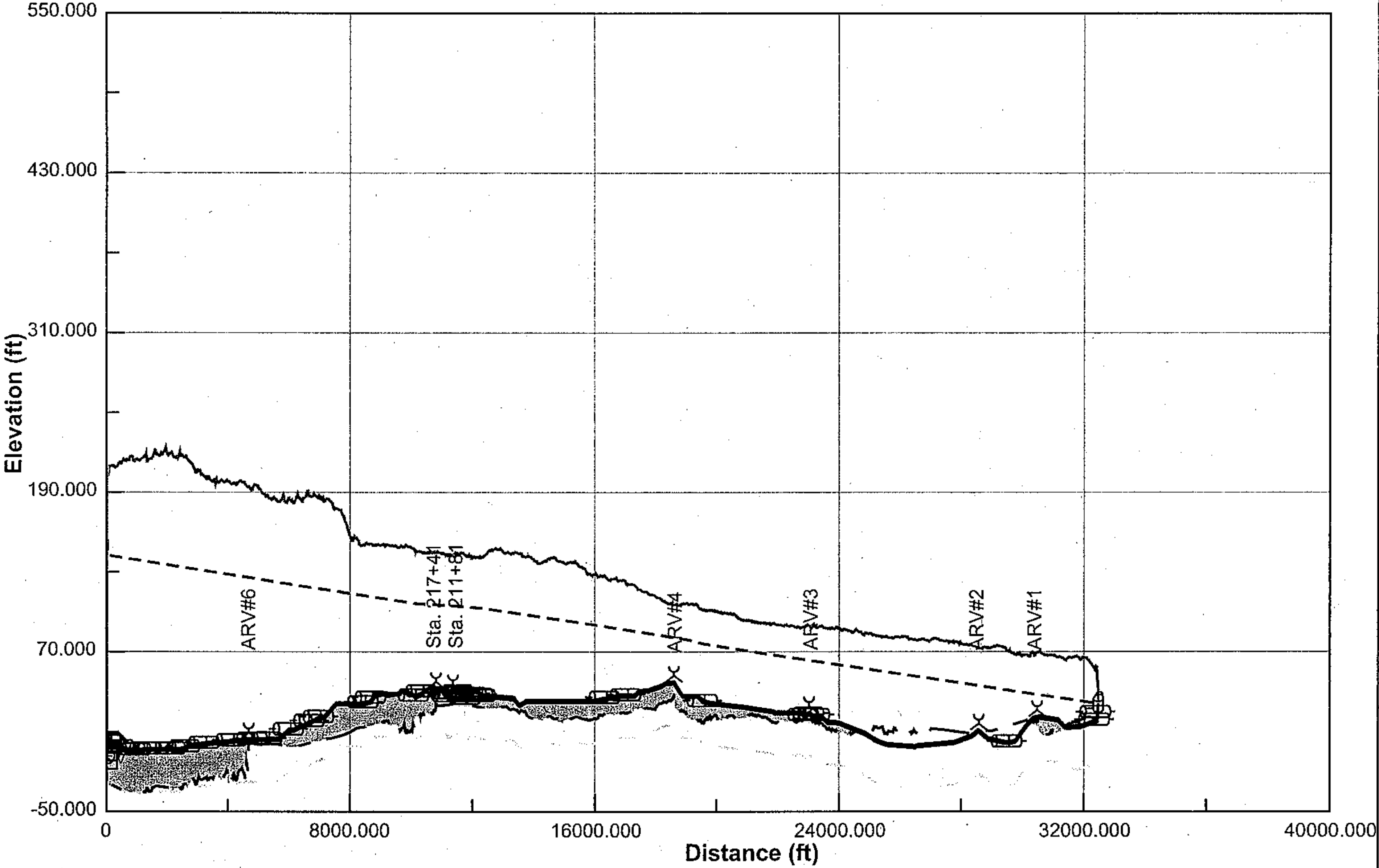
	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 2" Combination Air/Vacuum Valves - ARV#4 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
	www.haestad.com METHODS	Figure #25	



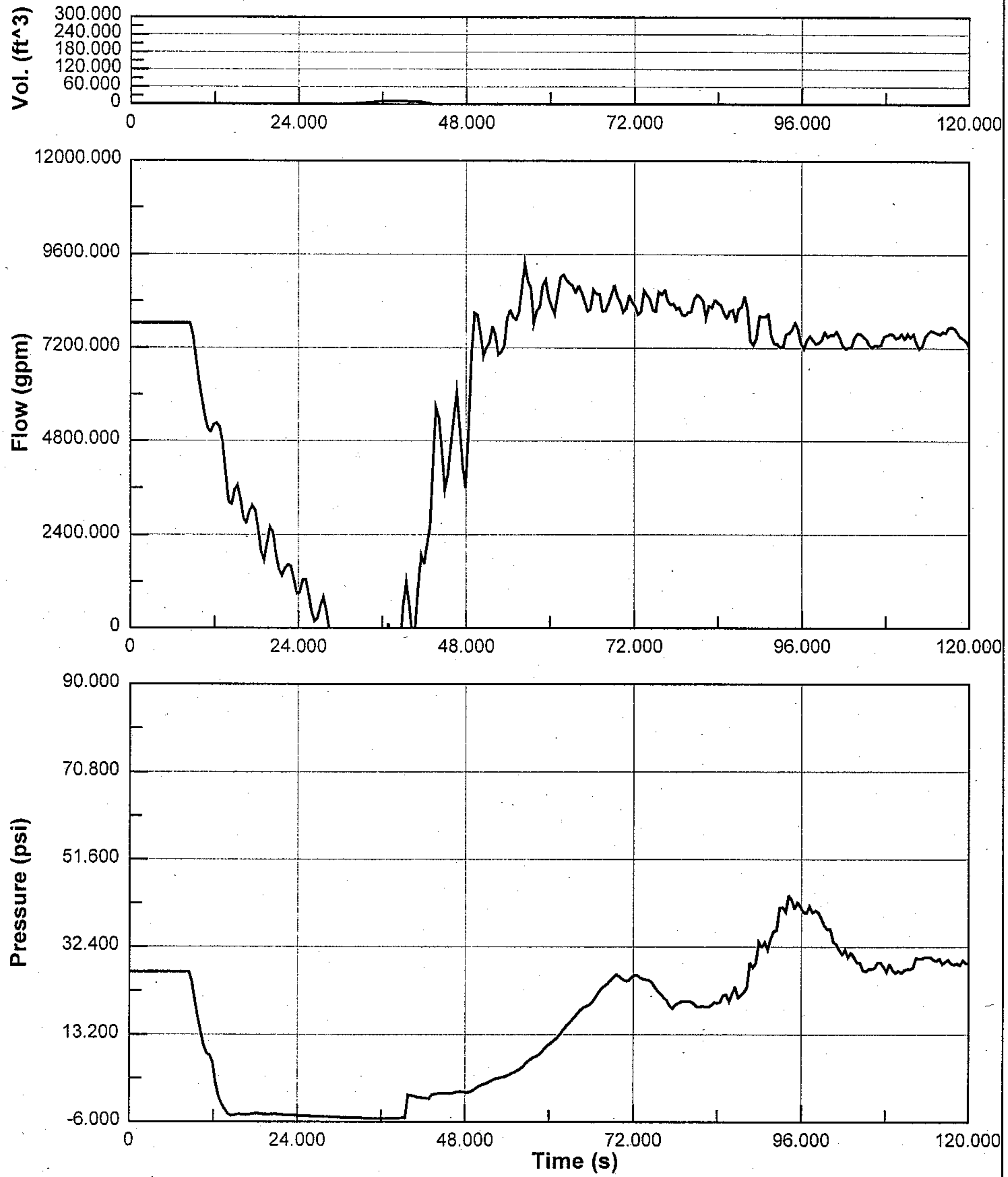
TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 2" Combination Air/Vacuum Valves - ARV#4 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Downstream)
www.haestad.com METHODS	Figure #26	



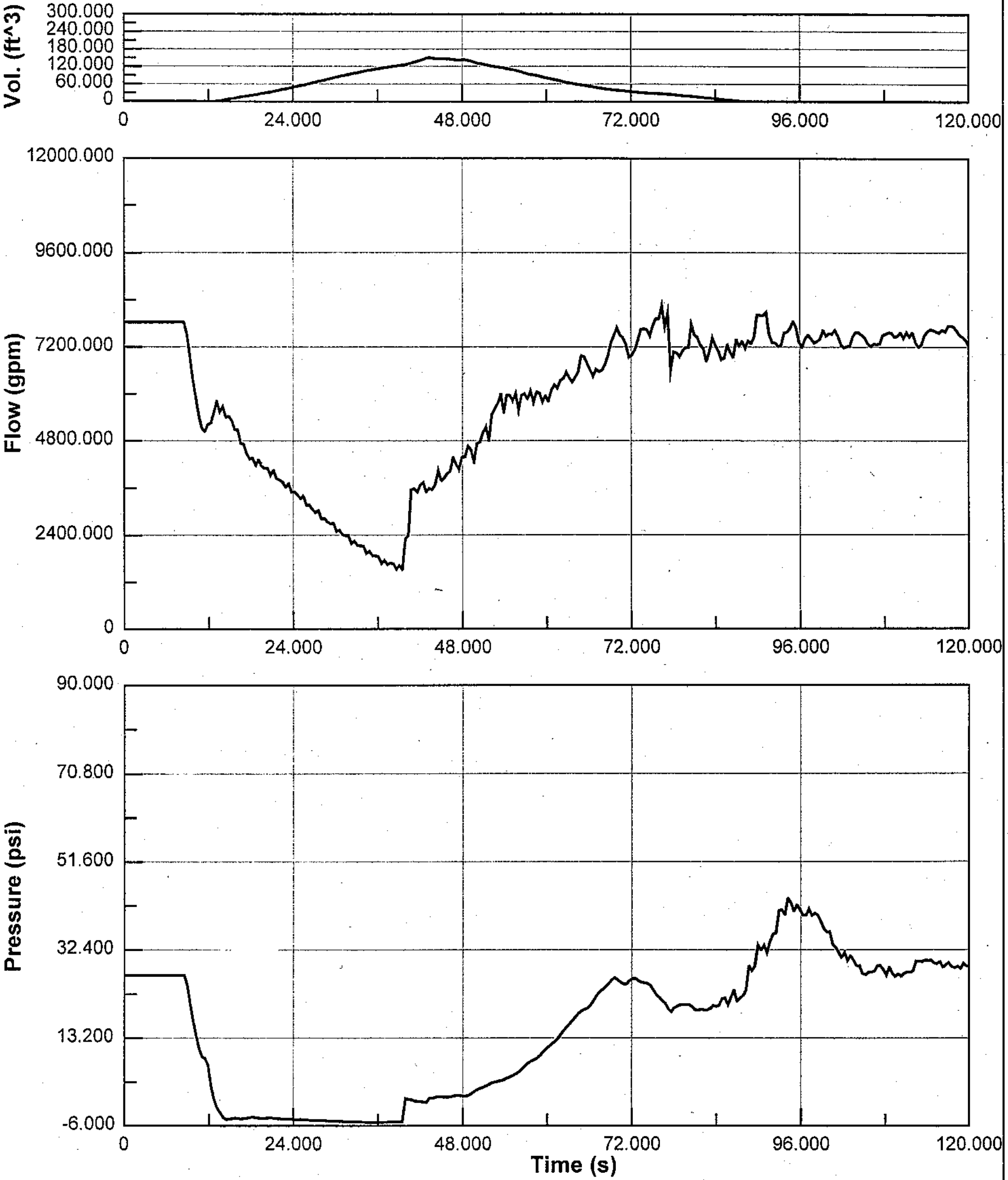
	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 1" Combination Air/Vacuum Valves - Pressure Envelope w/Pump Failure and Restart after 30 sec
	www.haestad.com METHODS	Figure #27	



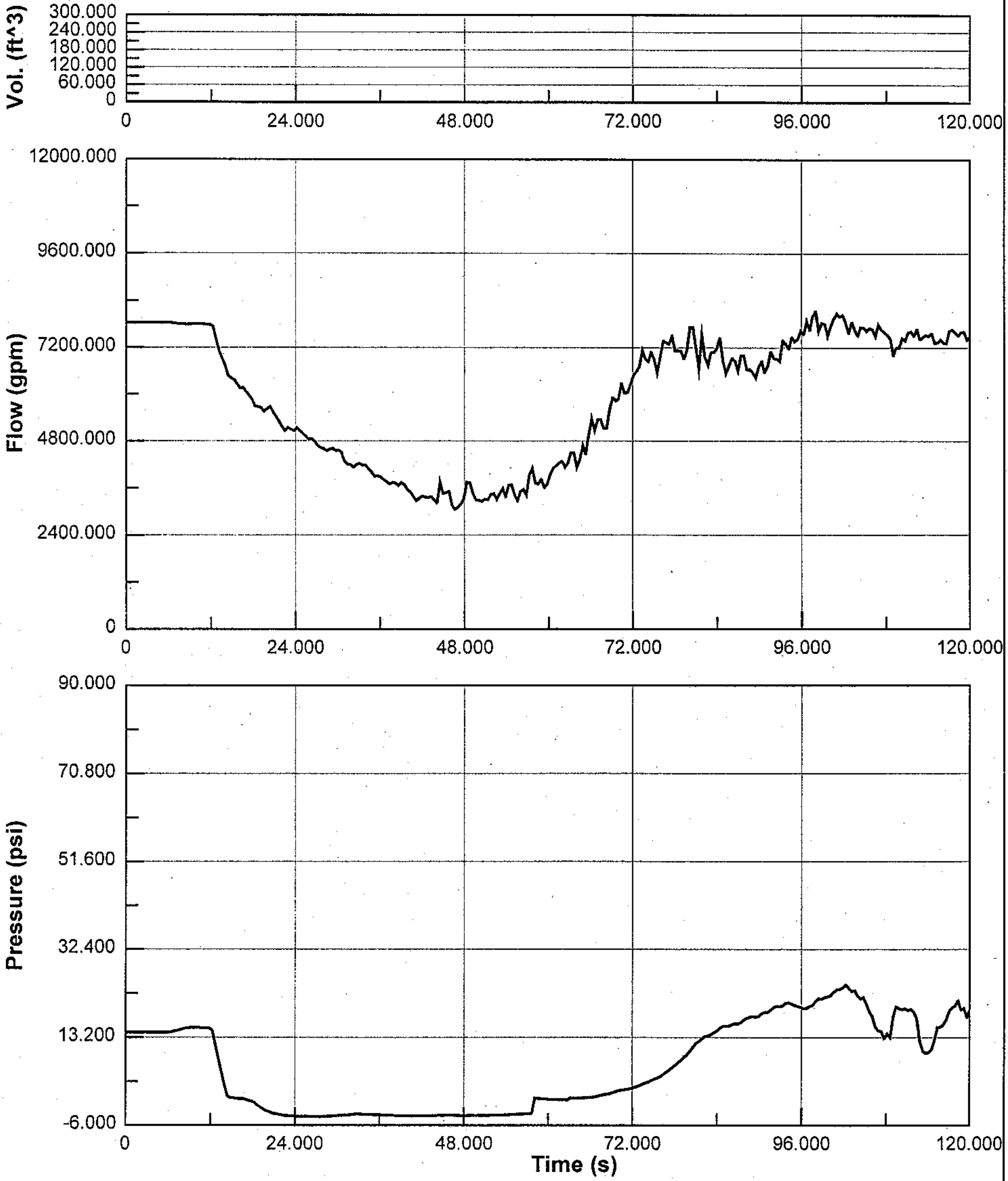
TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 1" Combination Air/Vacuum Valves - Pressure Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #28	



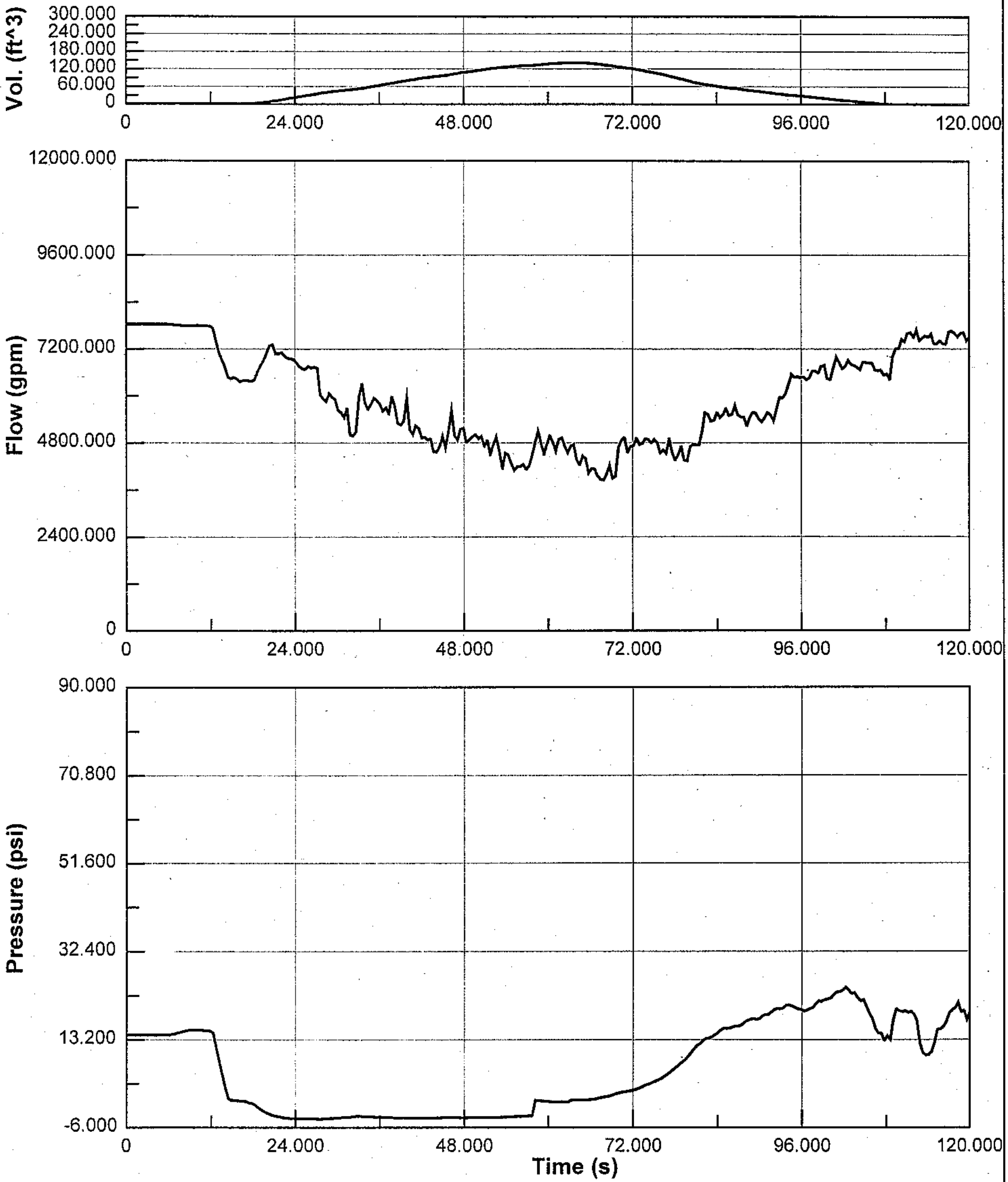
	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 1" Combination Air/Vacuum Valves - Sta. 217+41 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
	www.haestad.com METHODS	Figure #29	



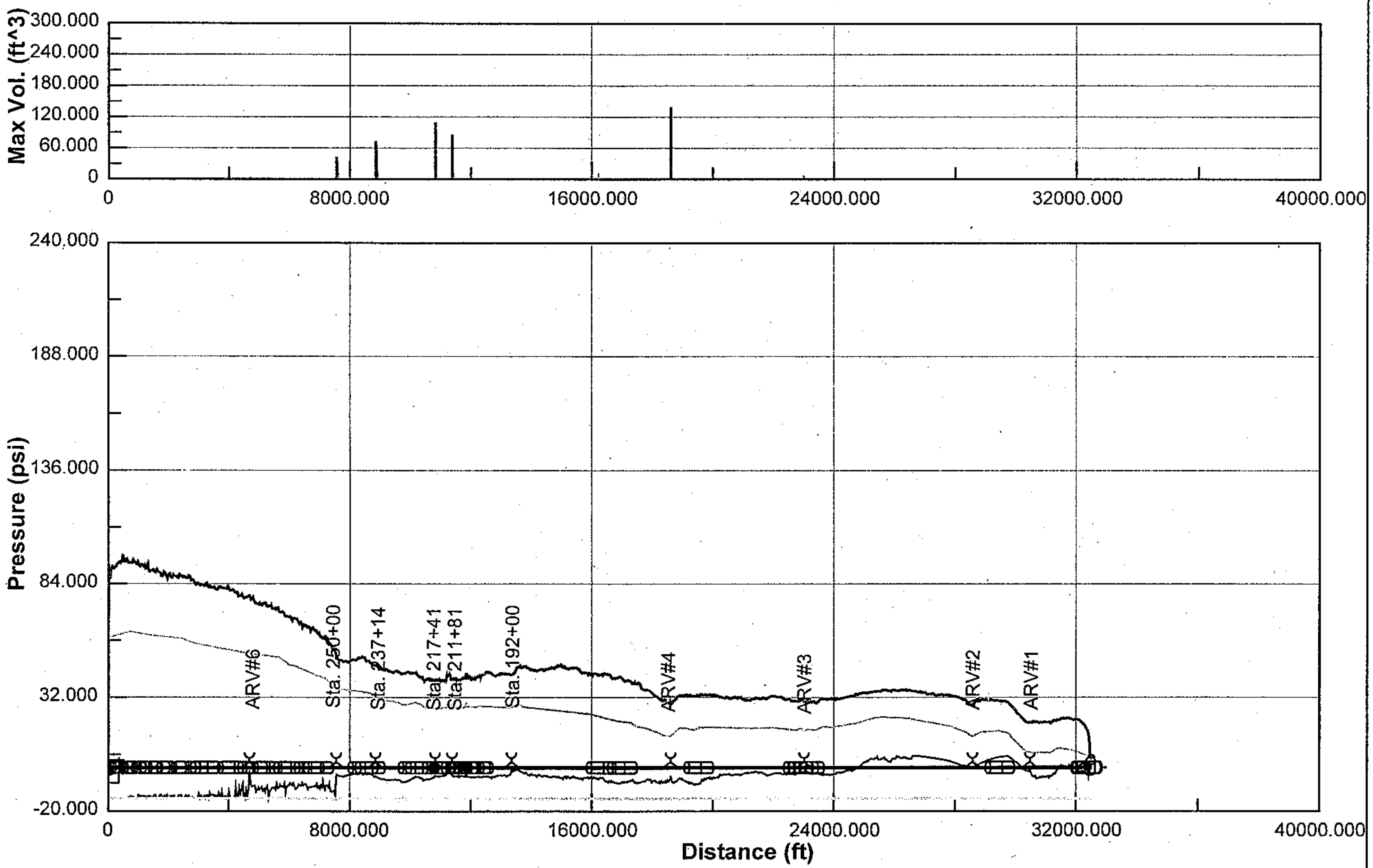
	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 1" Combination Air/Vacuum Valves - Sta. 217+41 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Downstream)
	www.haestad methods.com	Figure #30	



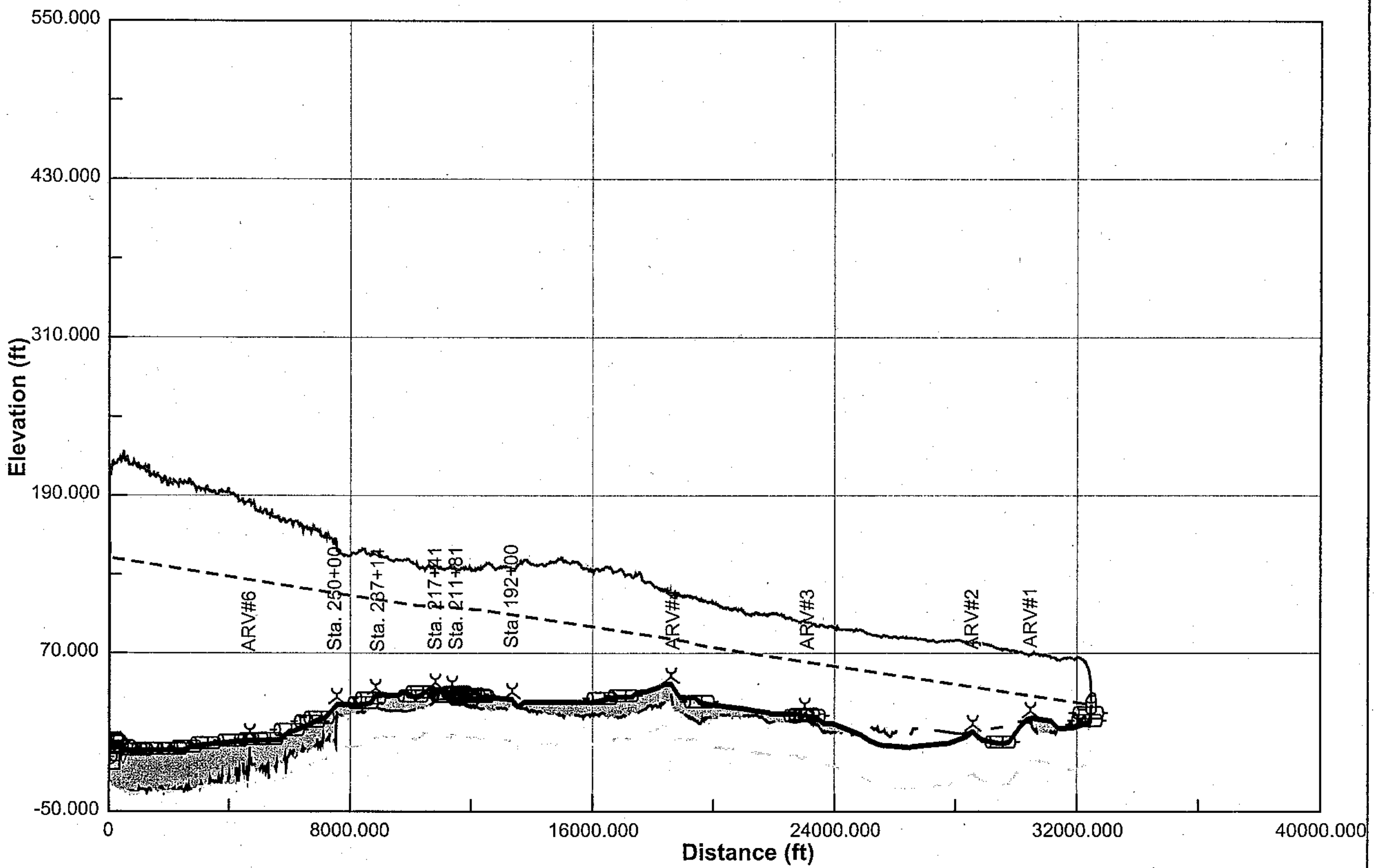
TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 1" Combination Air/Vacuum Valves - ARV#4 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Upstream)
www.haestad.com METHODS	Figure #31	



	TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with 1" Combination Air/Vacuum Valves - ARV#4 Pressure, Flow, and Volume Time History - w/Pump Failure and Restart after 30 sec (Downstream)
	www.haestad.com METHODS	Figure #32	



TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with Additional Valves - Pressure Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #33	



TM#3 - Surge Analysis	June 2006	PS 34 with Shipyard Relocation with Additional Valves - Head Envelope w/Pump Failure and Restart after 30 sec
www.haestad.com METHODS	Figure #34	

APPENDIX A

Wave Speed and Motor Inertia Calculations

NEI Surge Analysis - Wave Speed Calculations
Technical Memorandum #3
KHA Project No.: 011335022

5/31/2006
By: SL & DW

Calculate Wave Speed for Different Size Pipes and Material:

Korteweg Method:

$$a = \sqrt{\frac{\frac{E_v}{\rho}}{1 + \frac{E_v D}{Ee}\psi}}$$

Ev = Bulk Modulus of Elasticity (lb/ft^2) = 45,700,000
ρ = Liquid Density ($slugs/ft^3$) = 1.94
D = Pipe Internal Diameter (in)
e = Wall Thickness (in)
E = Young's Modulus for Pipe Material (psi)
a= Wave Velocity (ft/s)

AWWA C900 and C906 Method:

$$a = \frac{4700}{\sqrt{1 + \frac{KD_i}{Et}}}$$

K = Bulk Water Modulus (psi) = 300,000
E = Material Modulus of Elasticity (psi)
D = Pipe Internal Diameter (in)
t = Wall Thickness (in)
a= Wave Velocity (ft/s)

Korteweg Method:

Material:	Diam., D	Thick., e	D/e	Ev	E	ρ	ψ	μ	Celerity:	Celerity:
	(in)	(in)		(lbf/ft^2)	(lbf/ft^2)	($slugs/ft^3$)			(ft/s)	(m/s)
DIP	12.58	0.31	40.58	45,700,000	3,590,000,000	1.94	0.9216	0.28	3995	1218
DIP	16.72	0.34	49.18	45,700,000	3,590,000,000	1.94	0.9216	0.28	3865	1178
DIP	18.8	0.35	53.71	45,700,000	3,590,000,000	1.94	0.9216	0.28	3801	1159
DIP	20.88	0.36	58.00	45,700,000	3,590,000,000	1.94	0.9216	0.28	3744	1141
DIP	25.04	0.38	65.89	45,700,000	3,590,000,000	1.94	0.9216	0.28	3645	1111

AWWA Method:

Material:	Diam., D	Thick., t	D/e	K	E	Celerity:	Celerity:
	(in)	(in)		(psi)	(psi)	(ft/s)	(m/s)
HDPE	19.722	2.867	6.88	300,000	157,000	1,250	381
HDPE	21	2.364	8.88	300,000	157,000	1,109	338
PVC	23.61	1.032	22.88	300,000	400,000	1,103	336
PVC	29.28	1.28	22.88	300,000	400,000	1,103	336

Note: 1). Use Kortzeweg equation for D/e greater than 40. Use AWWA wave equation for D/e less than 40.
2). HDPE Modulus of Elasticity came from Fundamentals of Machine Elements by B. Hamrock, B. Jacobson, & S. Schmid © 1999.
3). The 21" inside diameter HDPE, used between PS 34 to Southside, thickness was estimated based on a DR 11 IPS sizing.

Calculate Moment of Inertia for each Pump:

$I_{pump} = 1.5 \times 10^7 \times (P/N^3)^{0.9956}$ kgm^2
$I_{motor} = 118 \times (P/N)^{1.48}$ kgm^2

P = Brake horsepower in kilowatts at the BEP
N = Rotation speed in rpm

Pump #:	P: (kW)	N: (rpm)	I_{pump} (kgm^2)	I_{motor} (kgm^2)	Total Inertia (kgm^2)
PS#34 Pump #1	61.6	826	1.76	2.53	4.29
PS#34 Pump #2	63.1	826	1.80	2.63	4.43
PS#34 Pump #3	193.6	842	5.20	13.40	18.60
PS#34 Pump #4	298.0	1180	2.91	15.39	18.30
PS#35 Pump #1	23.7	1092	0.29	0.41	0.70
PS#35 Pump #2	24.9	1092	0.31	0.44	0.75
PS#35 Pump #3	81.1	840	2.20	3.71	5.91
PS#35 Pump #4	86.4	1185	0.84	2.45	3.29

***All pump information taken from pump curves provided by City of Wilmington.**

Calculate Brake Horse Power for each Pump:

BHP = (Q x H x γ) / (550 x e)

Q = Flow rate at most efficient point
H = Head at most efficient point

γ = Density of water
e = Best efficieny point along pump curve

Pump #:	Q: (gpm)	Q: (cfs)	H: (ft)	γ: (lb/cf)	e: (%)	BHP (hp)	BHP (kW)
PS#34 Pump #1	3900	8.7	67	62.4	80%	82.6	61.6
PS#34 Pump #2	4000	8.9	67	62.4	80%	84.7	63.1
PS#34 Pump #3	8000	17.8	113	62.4	88%	259.7	193.6
PS#34 Pump #4	8200	18.3	160	62.4	83%	399.6	298.0
PS#35 Pump #1	2250	5.0	48	62.4	86%	31.7	23.7
PS#35 Pump #2	2500	5.6	46	62.4	87%	33.4	24.9
PS#35 Pump #3	4300	9.6	80	62.4	80%	108.7	81.1
PS#35 Pump #4	4100	9.1	85	62.4	76%	115.9	86.4

Kimley-Horn and Associates, Inc.

APPENDIX B

Pump Station Nameplate Data

Pump Station #34 Nameplate Data

#2 Motor – Serial #H58021

Wound Rotor Induction Motor
Frame SWU445UP
HP 100
Duty Cont
Hertz 60
Volts (PR1) 460
Volts (SEC) 360
INS Class F
Front Bearing 314 SF
Serial I14431
Type W.P.I.
Service Factor 1.15
Phase 3
RPM 865
AMPS (PRI) 150
AMPS (SEC) 130
Max C Amb 40
Rise C
Shaft Bearing 316 SF
Continental Electric Co.

Pump #2

Allis Chalmers
Model 300
Serial # 821-37D75-1-2
Size 10 x 10 x 21
Type NSWV - LC
G.P.M. 3500 HD FT 60
IMP. DIA. 20.75
R.P.M. 826

#3 Motor

Frame SNU586P
HP 300
Duty Cont
Hertz 60
Volts (PRI) 460
Volts (SEC) 550
INS Class F
Front Bearing 316 SF
Serial H58023
Type W.P.I.
Service Factor 1.15
Phase 3
RPM 880
AMPS (Pri) 372
AMPS (Sec) 255
Max ◦C AMB 40
Rise ◦C
Shaft Ext Bearing 316SF
No Name Tag

#4 Motor

Titan Inventer
U.S. Motors
Model G78370
Frame 5809P
RPM 594 to 1188
Volts 460 APMS 477
HPS 400 HZ 60

#4 Pump

ITT
Frame FB-K1

Pump Station #35 Nameplate Data

#2 Motor – Serial #458024

Continental Motor
Frame SWV404WP
HP 50
Duty Cycle Cont
Hertz 60
Volts (Pri) 480
Volts (Sec) 350
Bearings 314 SF
Type W.P.I.
Serv. Factor 1.15
Phase 3
AMP 1160
AMPS (Pri) 64
AMPS (Sec) 57
Pump has no name tag. Allis-Chalmers

#1 Motor Marathon

MLD# BE 40455FS13078ANW
Mounting F1 Frame 404 HPV
Serial# WAA003297
PH 3 Volts 230/460 HP 60 HZ 60
KW 44.76 F.L. Amps 146/73
Pump Allis Chalmers
Frame F7 – D2
INB Bearings U-1314-3
DB Bearings 5312

#4 ITT A-C Pump

Size 10 x 10 x 21 LG Type NSWV
Serial# 1-74827-04-1
GFM 4100 Head (FT) 85 RPM 1105
MLD# 300
Impellar Dia 17.12
Year 1994
Motor NJ Motor
MCB# G70372 HP 150 Frame 5006P
Volts 460 Amp 169 H260 Rating Cont. Design D
RPM 1186 Ser. Factor 1.15 PH3

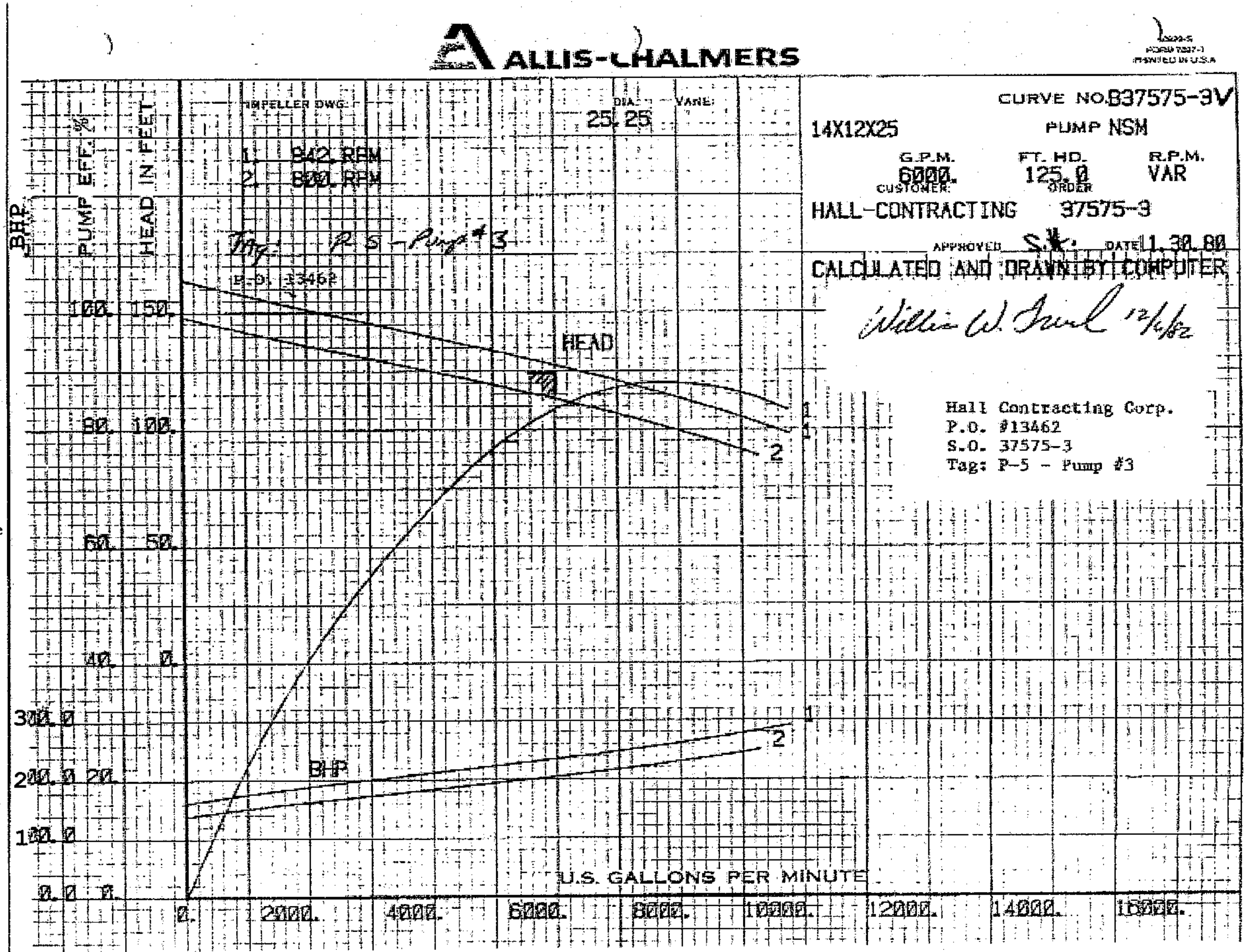
#3 Motor Continental

Frame SNV504P
Serial# H58026
HP 125 Type W.P.I.
Duty Cont. Ser. Factor 1.15
Hertz 60 Phase 3
RPM 880
Volts (Pri) 460 Amps 183 Primary
Volts (Sec) 885 Amps 150 Sec.
Front Bearing 314 SF
Shaft Ext. Bearing 314 SF
Pump no name tag. Allis-Chalmers

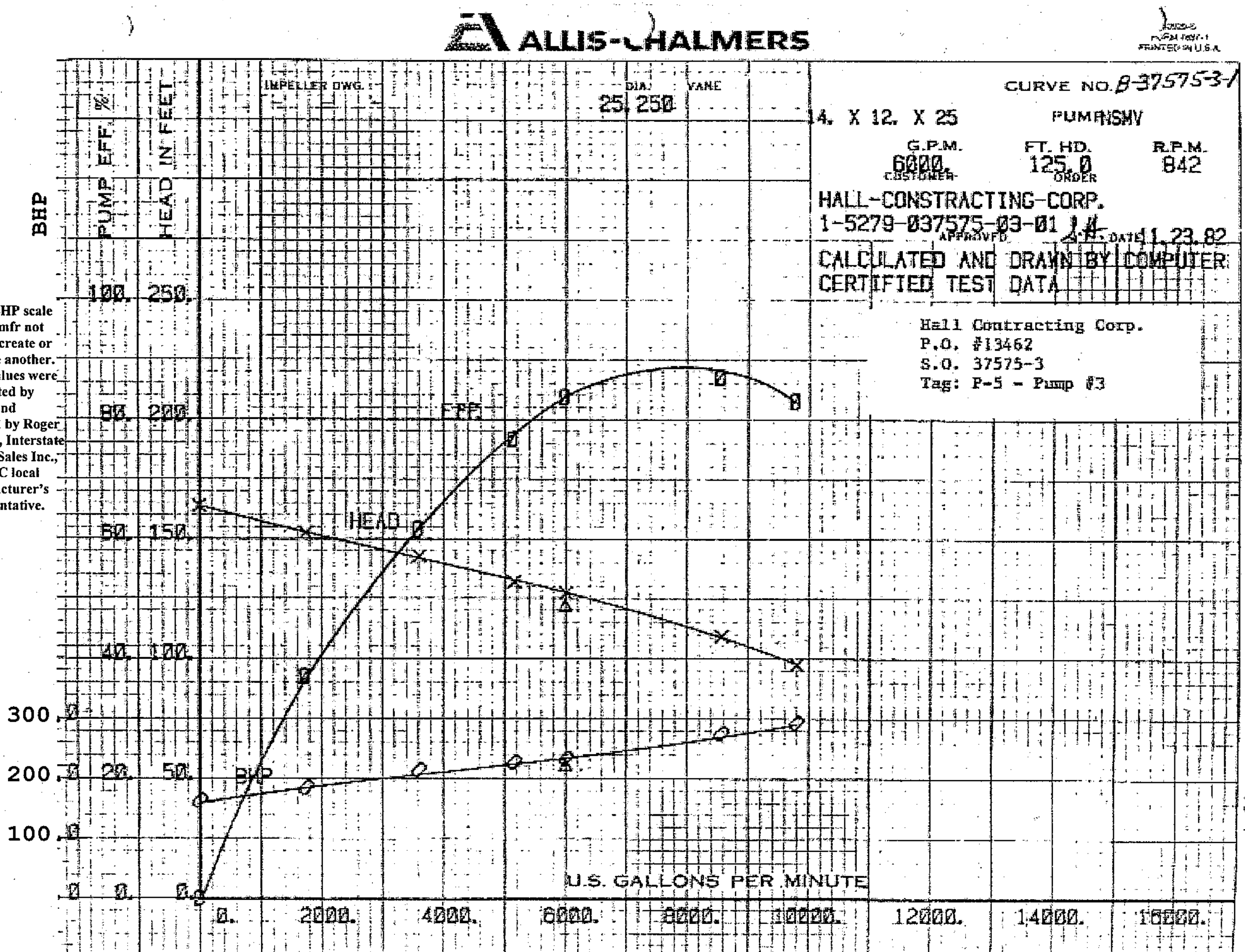
APPENDIX C

Pump Curves

Note: BHP scale cutoff; mfr not able to create or provide another. BHP values were calculated by COW and verified by Roger Wright, Interstate Utility Sales Inc., ITT A-C local manufacturer's representative.



Note: BHP scale cutoff; mfr not able to create or provide another. BHP values were calculated by COW and verified by Roger Wright, Interstate Utility Sales Inc., ITT A-C local manufacturer's representative.



Type NSM and NSMV
Performance Curves 1180 RPM

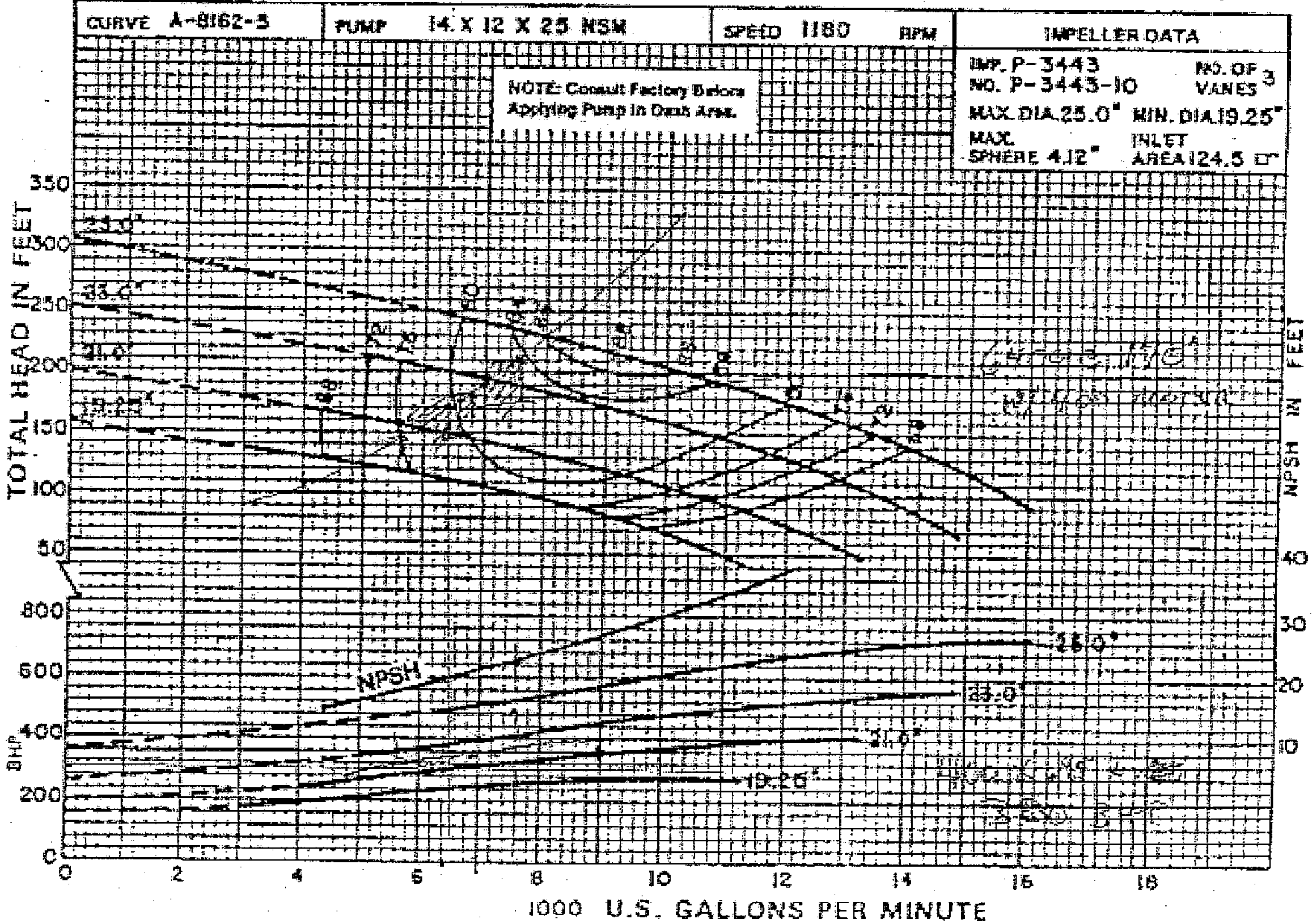
A unit of ITT Corporation

U824-0936 (24)

Impeller diameter = approx. 21", provided by Roger Wright, Interstate Utility Sales Inc., ITT A-C local manufacturer's representative.

P.S. # 34, Pump No. 4

Supersedes all pr



21" Impeller

Flow (gpm)	Head (ft)
0	200
1,000	192
2,000	185
3,000	178
4,000	170
5,000	161
6,600	147
7,000	143
8,000	131
9,000	120
10,000	107
11,000	91

23" Impeller

Flow (gpm)	Head (ft)
0	250
1,000	245
2,000	238
3,000	230
4,000	221
5,000	212
6,600	198
7,000	194
8,000	184
9,000	171
10,000	160
11,000	147

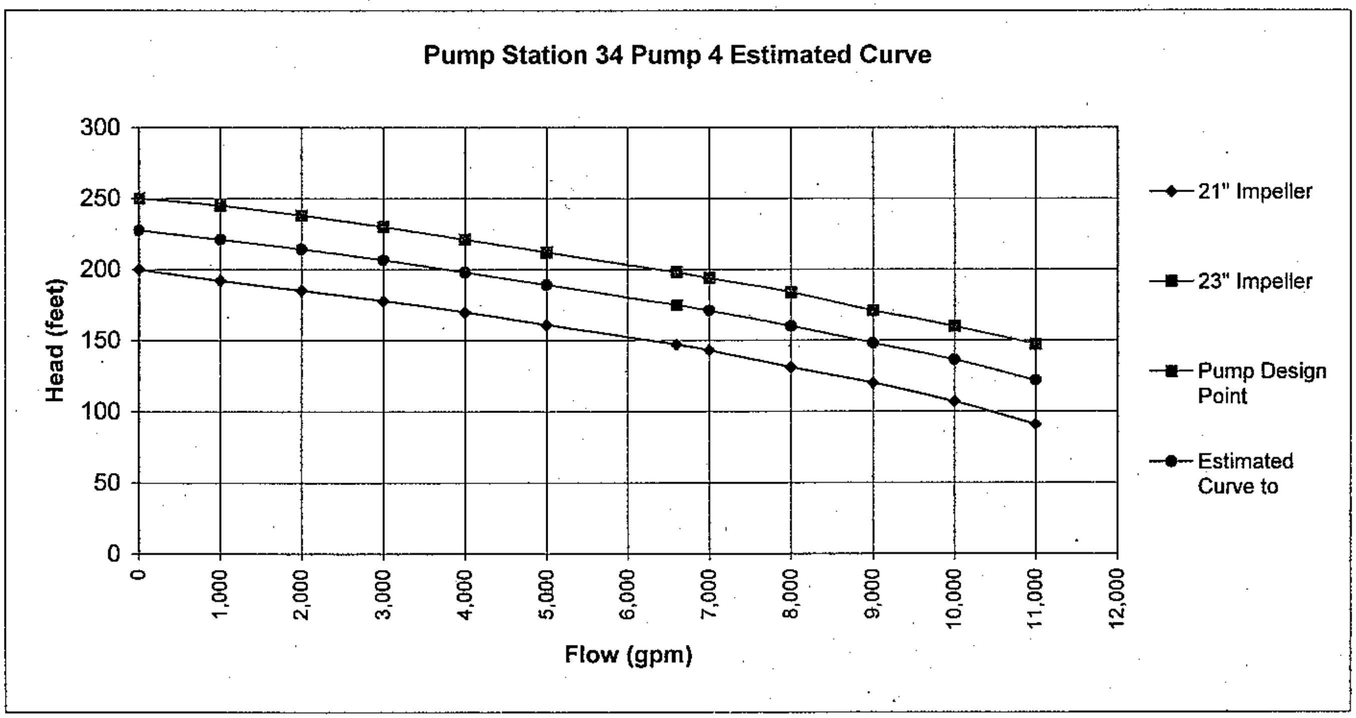
Estimated Curve to Meet Pump Design Point

Flow (gpm)	Head (ft)
0	228
1,000	221
2,000	214
3,000	207
4,000	198
5,000	189
6,600	175
7,000	171
8,000	160
9,000	148
10,000	136
11,000	122

Pump Design Point

Flow (gpm)	Head (ft)
6,600	175

% Diff	55%



APPENDIX D

Wrightsville Beach NEI Segment 1 Specification

WRIGHTSVILLE BEACH NEI SEGMENT 1

DIVISION 15 - MECHANICAL

SECTION 15A - SANITARY SEWERS

15A.1 SCOPE OF WORK: The work in this section consists of furnishing all plant, labor, and materials to construct all sanitary sewer lines and appurtenances as shown on the plans and in accordance with the specifications. The Contractor for Section II (General) is responsible for making the gravity sewer connection from the pumping station to the existing manhole on Parmele Blvd.

15A.2 CONSTRUCTION SURVEYS shall be performed as described under the paragraph for construction surveys in the Special Conditions.

15A.3 PIPE MATERIALS: Pipe shall be either:

A. Ductile iron pipe shall be used where designed on the plans and shall be push joint type. Pipe shall be Grade 60-45-10 ductile iron conforming to ASTM A339-55 and ANSI 21.51. Joints shall conform to ANSI 21.11. Pipe shall be Class 50.

B. Vitrified clay pipe, extra strength, conforming to ASTM C-700-74, with prefabricated resilient joints conforming to ASTM C-450 as revised.

15A.4 LAYING SANITARY SEWER LINES: Reference is here made to ASTM Specification C 12 "Recommended Practice for Laying Vitrified Clay Pipe", which is made a part of these documents by reference.

A. Excavation of Trench:

1. Mechanical excavation of trenches shall be stopped above the final invert grade elevation so that the pipe may be laid on a firm undisturbed native earth bed. If undercutting occurs, all loosened earth must be removed and the trench bottom brought back to grade as stated under the section for excavating, grading and backfilling.

2. Trench walls shall be restrained with adequate sheeting and shoring where directed by the Engineer.

3. Adequate dewatering including all points and other pump equipment shall be provided where required by the Engineer.

4. Excavation and trenches in rock shall be carried to a depth of one fourth of the diameter of the pipe, but in no case less than 4 inches below the pipe bottom, and shall be made by an acceptable method, including the use of explosives under local, legal limitations.

5. Width of trenches shall provide adequate space for workmen to place and joint the pipe properly, but in every case the trench wall shall be held to a maximum slope of three (3) feet vertically to one (1) foot horizontally.

3. Backfill: Care shall be taken in placing backfill material over the installed pipeline as to not disturb its alignment and grade. The pipe trench shall be backfilled back to the elevation of the surrounding bottom.

C. Banks Channel Installation: Requirements for this pipeline installation are the same as Inland Waterway Crossing with the exception that the spoil can be placed on the bottom 10 feet to 20 feet from the excavated trench and backfilled over the pipeline after installation.

D. Permits: The required permits for the subaqueous crossings from the N. C. Coastal Management Office and the U.S. Army Corps of Engineers are attached. The requirements and conditions set out by both permits are made part of the contract requirements for this work.

15B.5 JOINTING: Jointing shall be accomplished in accordance with the pipe manufacturer's recommendations, subject to the approval of the Engineer. For mechanical joints, the normal range of bolt torque of 3/4-inch bolts shall be between 60 and 90 foot pounds. When tightening bolts, it is essential that the gland be brought up toward the pipe flange evenly, maintaining approximately the same distance between the gland and the face of the flange at all points around the socket. This shall be done by partially tightening the bottom bolt first, then the top bolt, next the bolts at either side, and last the remaining bolts. Repeat this cycle until all bolts are within the above range of torques. If effective sealing is not attained at the maximum torque indicated above, the joint shall be disassembled, cleaned thoroughly and reassembled. Bolts shall not be overstressed to compensate for poor installation. Push joints shall be made in conformance with the manufacturer's recommendations. Where stainless steel bolts are shown on the drawings, these shall be Type 304 stainless steel.

15B.6 CUTTING PIPE: Where necessary to cut a length of ductile iron pipe, such cutting must be done in accordance with "Installation of Gray and Ductile Cast Iron Mains....", ANSI/AWWA C600-77. In any case, pipe broken or cracked or otherwise made unfit for use by the cutting shall be charged to the Contractor. After the pipe has been cut, it shall not be installed until the Engineer has given his approval of the cut piece of pipe proposed for use. Polyethylene piping shall be cut in accordance with the manufacturer's recommendations.

15B.7 VALVES AND VALVE BOXES:

A. Plug valve shall be eccentric plug type, mechanical joint semi-steel, 1/4 turn, non lubricated or permanently lubricated. Valves shall have gear operator fully enclosed for underground service with 2 inch square operating nut. All wetted surfaces shall be plastic coated. Valves shall be Dezurick Series 100, Homestead, Dresser or equal.

B. Air release valve shall be 2" sewage air release valve with cast iron body and stainless steel, Type 4240 float and operating mechanism. The valve shall allow entrapped air or gases to vent from the force main and to close once the rising wastewater operates the float. Valve shall be furnished with 2" shut-off gate valve, one inch blow off valve and 1/2" shut off valve, quick disconnect coupling and back flushing hose. Air release valve shall be installed in air release valve manhole as detailed on Plan Sheet No. 10. Valve shall be manufactured by APCO Valves of the Valve and Primer Corp., Val-Matic

Valve and Manufacturing Corp., or equal.

C. Valve Boxes shall be cast iron, telescoping type conforming to ASTM A48-48, Class 30, with 12-inch tap section and bottom section length as required for valve bury.

15B.8 BLOCKING: Thrust restraint shall be accomplished by concrete blocking at all bends and tees. Minimum dimensions shall be as indicated in the drawings. Concrete shall have a minimum compressive strength of 2,500 psi. No separate payment shall be made for concrete blocking. Blocking shall be included in the unit price per foot of pipe. In lieu of concrete blocking, restrained joints may be provided for a distance of 50 feet in each direction from the fitting used in the deflection of the line.

15B.9 PAVEMENT AND STRUCTURE REPAIR AND REPLACEMENT: The Contractor shall restore all pavement, sidewalks, driveways, curbs, gutters, culverts, drain lines and structures removed or disturbed as a part of the work to a condition equal to that before the work began. No permanent pavement shall be restored unless and until in the opinion of the Engineer, the condition of the backfill is such as to properly support the pavement.

15B.10 TESTING: The force main shall be pressure tested in accordance with AWWA Standard C600. Any discrepancy of the system to meet these tests shall be corrected by the Contractor at no expense to the Owner. Tests shall be at 100 psi for two hours duration.

15B.11 FINAL CLEANUP: Before final acceptance, the entire area covered by the work shall be cleared of all construction material, debris, broken pipe or other extraneous material and moved by the Contractor.

15B.12 MEASUREMENT: Measurement shall be made along the centerline of the pipe including all fittings from actual points of beginning as shown on the plans to termination. Pavement repair will be measured by linear foot of ditch across pavement areas.

15B.13 TUNNELING AND JACKING: At various locations where indicated or directed, the Contractor shall tunnel and jack mains under paved roads in lieu of cutting pavement. This generally will apply to mains under State highway roads. Mains shall be installed in steel casings tunneled under the pavement with the main threaded through the casing. Jacking and casing will be paid for at the prices per foot bid for the size and length installed. Casing shall be seamless or spiral welded steel piping, wall thickness as follows:

Nom. Size (Inches)	Min. Wall Thickness (Inches)	Carrier Pipe & Type
24"	.250	14" D.I.

Payment for casing and jacking shall be in addition to payment for installation of the lines. Piping installed in casings shall be supported on treated timber skids as shown on the drawings. Cost of skids shall be included in the casing price.

15B.14 LOCATION OF FORCE MAINS IN RELATION TO WATER MAINS: The horizontal separation between force mains and water mains shall be 10 feet. The minimum